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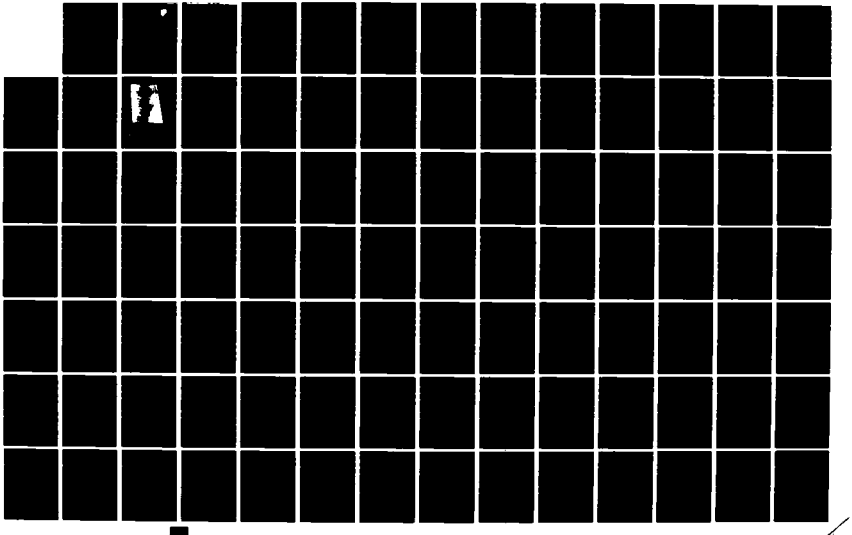

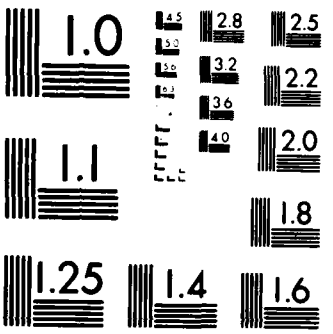

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RADC-TR-84-178
Final Technical Report
September 1984

DIGITAL CHANNEL EFFICIENCY MODEL

M/A-COM DDC, Inc.

D. R. Lowe

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Griffiss Air Force Base, NY 13441

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes the design, fabrication, and testing of a bit rate reduction system. The Digital Channel Efficiency Model (DCEM) effectively doubles the transmission bandwidth (number of channels) of digital communications systems, by providing an overall 2:1 compression of DCM signals, either DCS or NATO, transparent to any users, with no modifications of existing equipment. The DCEM also provides a variety of DCS-NATO interface modes at the digroup level.

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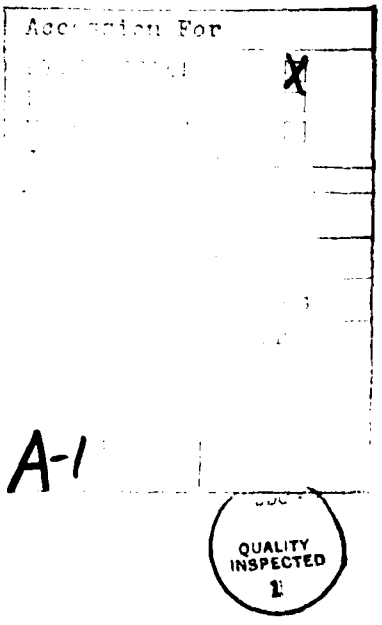

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SECTION 1.0
INTRODUCTION

1.1 SUMMARY OF STATEMENT OF WORK

The objective of this contract was to design, develop, fabricate, test and economically evaluate the interface and compression unit known as the Digital Channel Efficiency Model (DCEM). The work also included a separate study on CVSD.

1.2 STRUCTURE OF THE DOCUMENT

The first section includes introductory material to the DCEM program and references the documents specific to the program. Section 2.0 contains a description of the DCEM and summarizes the modes of operation, describes the equipment, and reviews its specification. Section 3.0 is a functional description of the DCEM. It provides analysis of the compression algorithms and discusses implementation. Section 4.0 is a summary of the testing program and Section 5.0 presents conclusions and recommendations from the program.

1.3 ASSOCIATED DOCUMENTS

There are several documents generated on the DCEM program which supplement the final technical report but were submitted as a separate document. The documents are listed below with a brief description of what is contained in each.

1.3.1 DCEM Test Report

The DCEM Test Report DCC-1664-184-TR-2562 describes the test results from the acceptance test, field test, and operations test and evaluation.

1.3.2 Reliability Prediction Report

The Reliability Prediction Report DCC-1664-883-2371 demonstrates that the DCEM exceeds the 3500 MTBF requirement of the program.

1.3.3 Maintainability Prediction Report

The Maintainability Prediction Report indicates the DCEM's mean corrective maintenance time (MCT), maximum-corrective-maintenance time (MmaxCT) and preventive maintenance time.

1.3.4 CVSD Study

The CVSD study, performed as part of the DCEM program, is presented in the CVSD Study Final Report DCC-1664-1081-FR-00-1334.

1.3.5 EMI Test Report

The EMI Test Report presents the results of the MIL-STD-462 testing performed on the DCEM.

1.4 APPLICABLE REFERENCES

1) "Prime Item Development Specification For Digital Channel Efficiency Model (DCEM)," Rome Air Development Center, Specification No. 0787793900, April 3, 1980.

2) "Multiplexer-Demultiplexer AN/FCC-98 ( ) ( ), "U.S. Army Communications Electronics Engineering Installation Agency, Specification CCC-74047.

3) "Multiplexer-Demultiplexer TD-1193 ( )/F, "U.S. Army Communications Electronics Engineering Installation Agency, Specification CCC-74048.

4) "Orange Book-Line Transmission," CCITT Volume III-2, Section 7, 1977.

5) Model 6019 Digital Channel Efficiency Model (DCEM) Operation and Installation Manual, DCC-1664-1283-OM-2604.

6) Digital Channel Efficiency Model Test Report, DCC-1664-184-TR-2562.

7) Reliability Prediction Report for Digital Channel Efficiency Model DCC-1664-883-2371.

8) Maintainability Prediction Report for the Digital Channel Efficiency Model.

9) CVSD Study Final Report DCC-1664-1081-FR-00-1334.

10) EMI Test Report on the Digital Channel Efficiency Model.

SECTION 2.0
DCEM DESIGN REQUIREMENTS

2.1 PURPOSE OF THE DCEM

The DCEM (see Figure 2-1) is designed to provide an effective 2:1 gain in the first order multiplex transmission facility requirements by utilizing Digital Speech Interpolation (DSI) and adaptive differential pulse code modulation (ADPCM) techniques. In addition the DCEM solves the interoperability problems caused by the differing North American Bell D2/D3/D4 standards and the European CEPT standard.

Below is a list of the DCEM features:

- Twofold increase in capacity of E1 or T1 channels using ADPCM/DSI techniques
- Format and rate conversion between the North American DSX-1 and the European CEPT standards
- Toll quality speech performance
- Voice band data channels detected and passed over 64 kbps PCM channel
- Signaling tones detected and passed transparently
- All the input and output circuits can be monitored and controlled individually via the keypad and display or an optional CRT

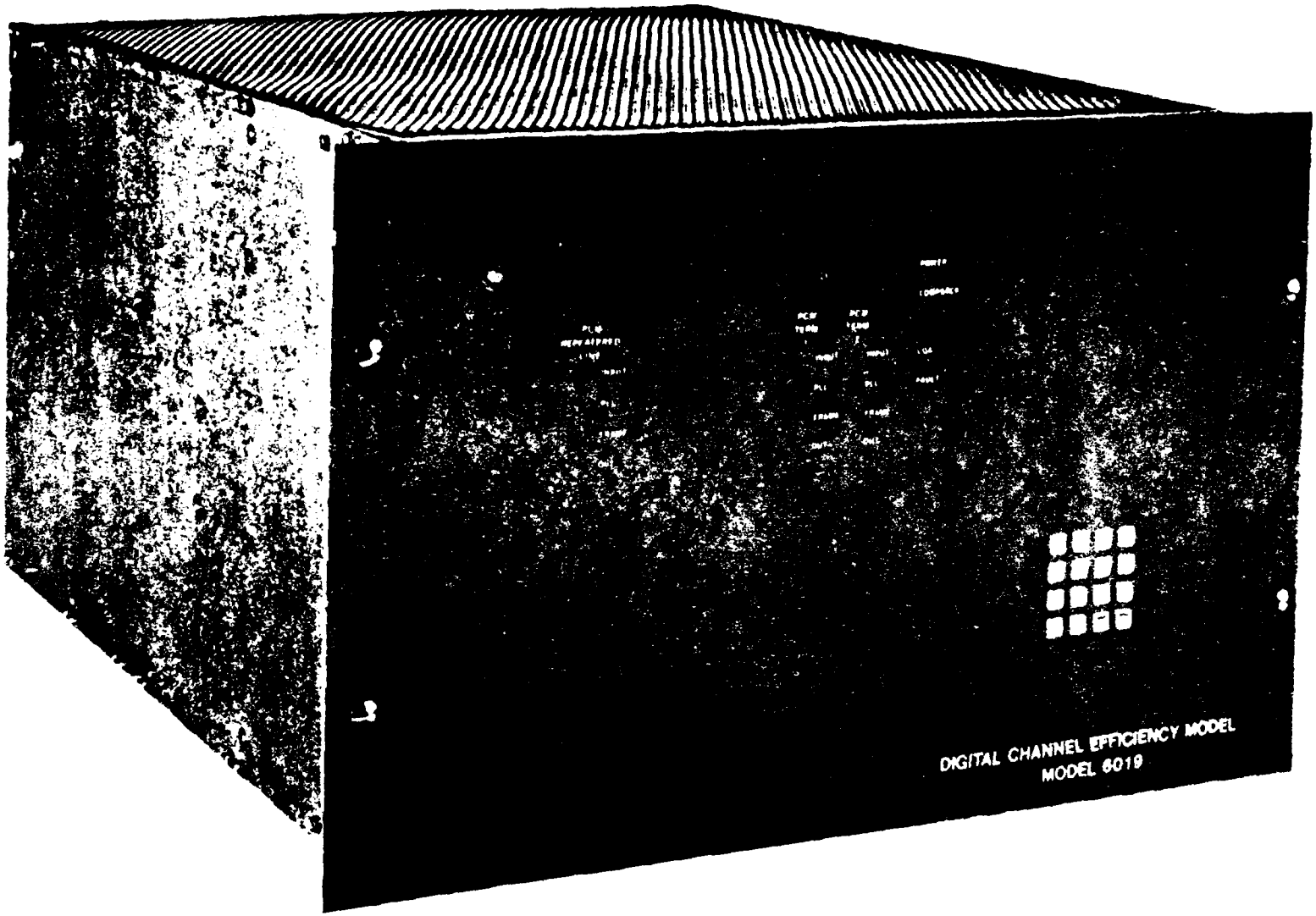


Figure 2-1. DCEM from DCC-2604

- Can be used over any digital transmission facility, i.e., satellite, microwave, fiber optics, coaxial, and metallic cable.

2.2 SUMMARY OF MODES

Below is a brief description of the operating modes of the DCEM. More details will be found in later sections which describe the various compression and conversion algorithms.

The DCEM has the capability of operating in nine modes of operation. These nine modes can be classified into three major functional groups: speech compression, rate conversion, and format conversion. The modes, labeled A through I, are shown in Figure 2-2. Modes A, B, C, and I are the speech-compression modes. Rate conversion is accomplished in modes D and E. Modes F, G, and H are format conversion modes. These three functional groups are described below.

2.2.1 Speech Compression

Modes A, B, C, and I are the speech compression modes. In these modes, the DCEM applies Digital Speech Interpolation and Adaptive Differential Pulse Code Modulation to the speech channels to reduce the overall bandwidth required. In mode A, the 1.544 Mbps outputs of two D2/D3 compatible channel banks are compressed onto a single 1.544 Mbps transmission facility. Mode B is similar to Mode A, but it allows the use of a 2.048 Mbps transmission facility. Mode C compresses the 2.048 Mbps output of a CEPT channel bank onto a 1.544 Mbps transmission facility. In Mode I, the 2.048 Mbps outputs of two CEPT compatible channel banks are compressed onto a single 2.048 Mbps transmission facility.

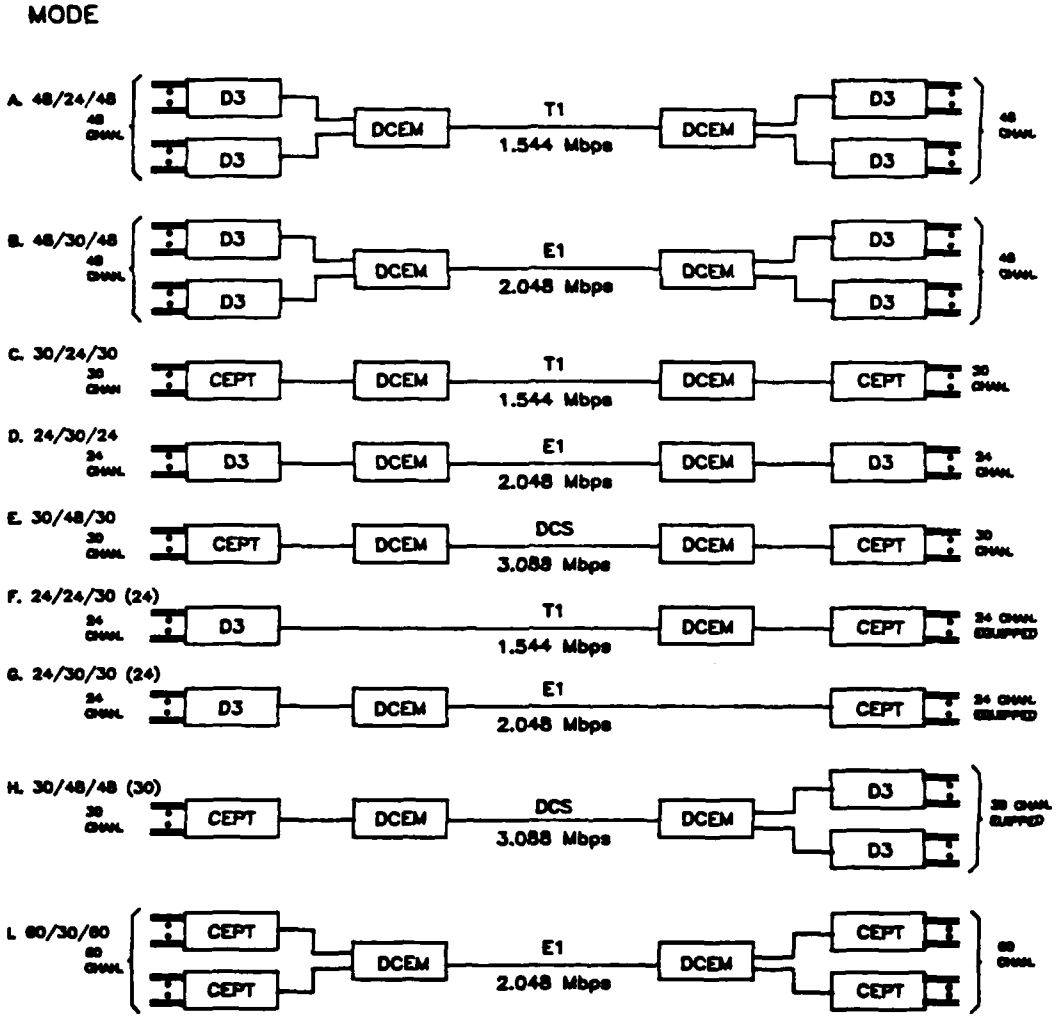


Figure 2-2. DCEM Operational Modes

The DSI/ADPCM concept consists of the use of an activity detector, so that bits are not allocated to inactive channels. Also, ADPCM is used instead of PCM during heavy loading. This is a technique by which the difference between the PCM input and a predicted PCM value is transmitted, instead of the PCM input. This method maintains the signal-to-noise ratio at high levels. Data channels (which can be either digital data channels selected by the DCEM operator or voice-band modem channels detected by the DCEM) are not compressed but are sent around the compression algorithms and transmitted as 64 kbps channels.

Statistical data concerning the DCEM traffic is provided to the DCEM operator approximately every 66 minutes while operating in these speech-compression modes.

2.2.2 Rate Conversion

The rate-conversion modes are D and E. In these modes, the incoming bit stream is simply stuffed up to the desired rate by adding framing and fill bits to each frame of data. The receive side extracts the original data stream by removing the framing and fill data. For mode D, 1.544 Mbps compatible channel bank or facility can be transmitted over a 2.048 Mbps transmission facility. In the 30/48/30 mode (Mode E), any 2.048 Mbps CEPT channel bank or facility using HDB3 line encoding can be transmitted over a DCS 3.088 Mbps transmission facility.

2.2.3 Format Conversion

Modes F, G, and H are the three format conversion modes. In these modes of operation, the DCEM allows communication between the North American D2/D3/D4 channel banks and the European CEPT channel

bank format by converting the data stream from one format to the other. Only one DCEM is required when the transmission facility is compatible with one of the two channel banks. Features of these modes are: companding conversion in accordance with the CCITT, signaling conversion between the two standards, and the forcing off of unequipped channels.

2.3 EQUIPMENT DESCRIPTION

There are two primary DCEM configurations: a full-capability DCEM that can perform speech compression, rate conversion, and format conversion and a Rate Conversion/Format Conversion DCEM that cannot perform speech compression. These two primary DCEM configurations are discussed in Subsections 2.3.1 and 2.3.2.

In addition, for both of the configurations mentioned above, there is a choice of input voltage. The DCEM can use 115 V ac, 230 V ac, or -48 V dc as its input voltages. A DCEM unit configured for either the 115 V ac or the 230 V ac voltage can easily be converted to the other ac voltage, and back. Converting from either of the ac voltages to the -48 V dc input voltage, or vice versa, can only be accomplished through the procurement of an additional power supply unit.

2.3.1 Full-Capability DCEM Configuration

The DCEM consists of a chassis, power supply, keypad, two eight-character LCD displays, and nine printed circuit boards. The configuration of the PC boards can be seen in Figure 2-3, which shows a front view with the front panel removed. The DCEM cards are the Speech Expansion Unit (SEU), the Frame Builder (FB), and Signal and Clock Recovery Unit (SCR), the Speech Compression Unit (SCU), the

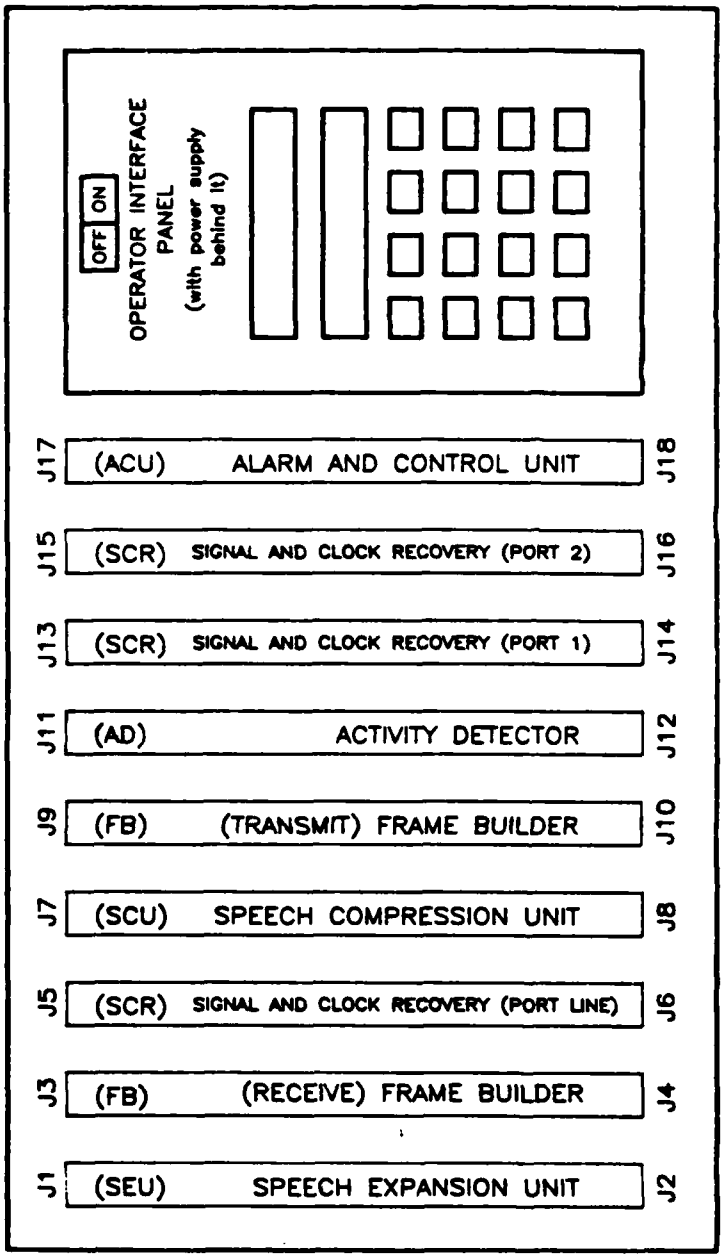


Figure 2-3. Full-Capability DCEM Front View, Front Panel Removed

Activity Detector (AD), and the Alarm and Control Unit (ACU). Note that there are three SCR cards and two FB cards.

Figure 2-4 shows the DCEM rear panel with its five Input/Output Interface Ports. The port at location J1 connects to the customer's alarm equipment. The J2 port is a standard RS-232C interface, which can be connected either to a printer or a console device. The J3 and J4 ports connect to the customer's channel banks and the J5 port to the transmission facility. Connections to these five ports are made through standard 25-pin EIA D-type male connectors. There is also an Error-Rate monitor output through a BNC plug.

2.3.2 Rate Conversion/Format Conversion DCEM Configuration

Like the full-capability DCEM, the Rate Conversion/Format Conversion DCEM has a chassis, power supply, keypad, and two eight-character LCD displays. However, it has five PC boards, rather than nine. As can be seen in Figure 2-5, which is a view of this DCEM with its front panel removed, these five boards consist of two Frame Builders, one Alarm and Control Unit, and two Signal and Clock Recovery Units. The Rate Conversion/Format Conversion DCEM's rear panel is identical to the rear panel of the full capability DCEM.

The Rate Conversion/Format Conversion DCEM includes all of the functions that the full-capability DCEM has in its rate conversion and format conversion modes (see Subsection 2.2 for a discussion of these modes).

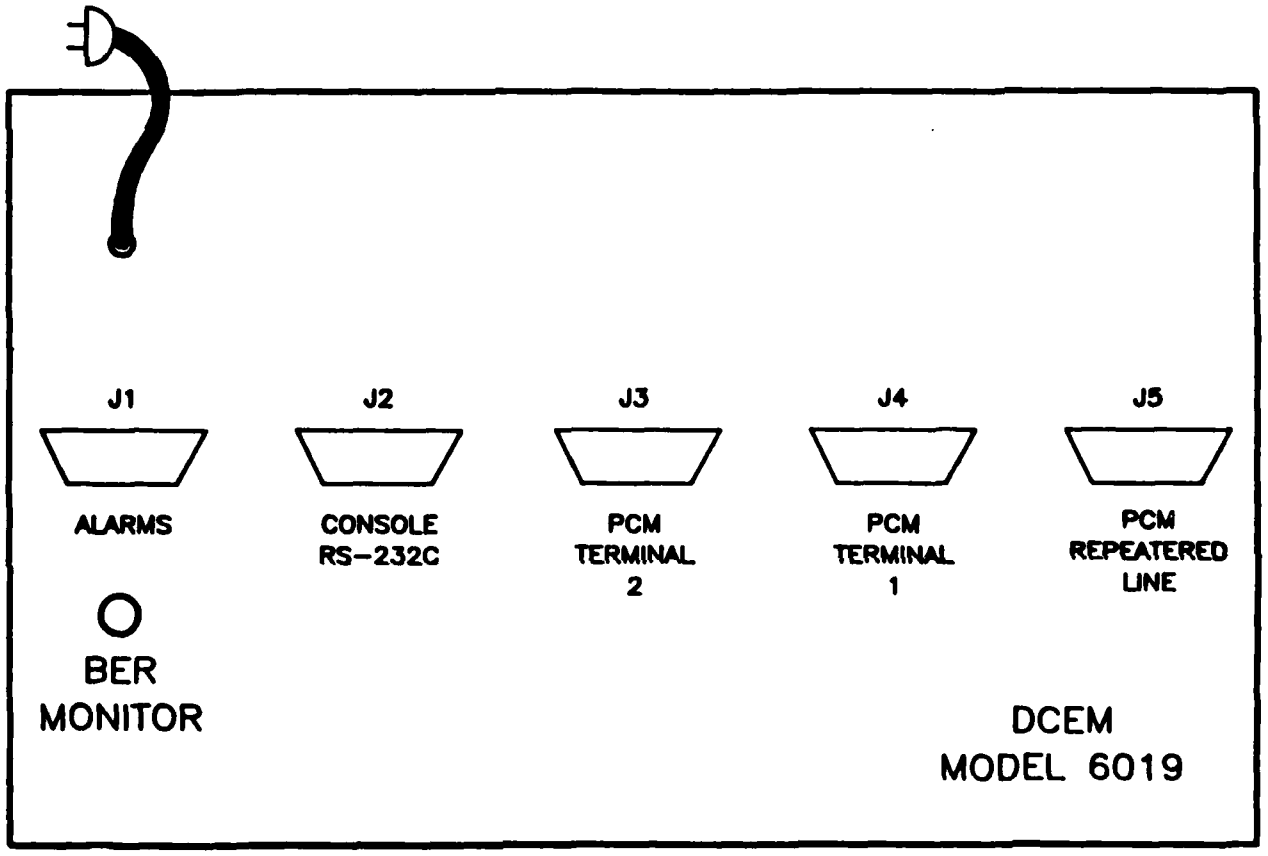


Figure 2-4. DCEM Rear View

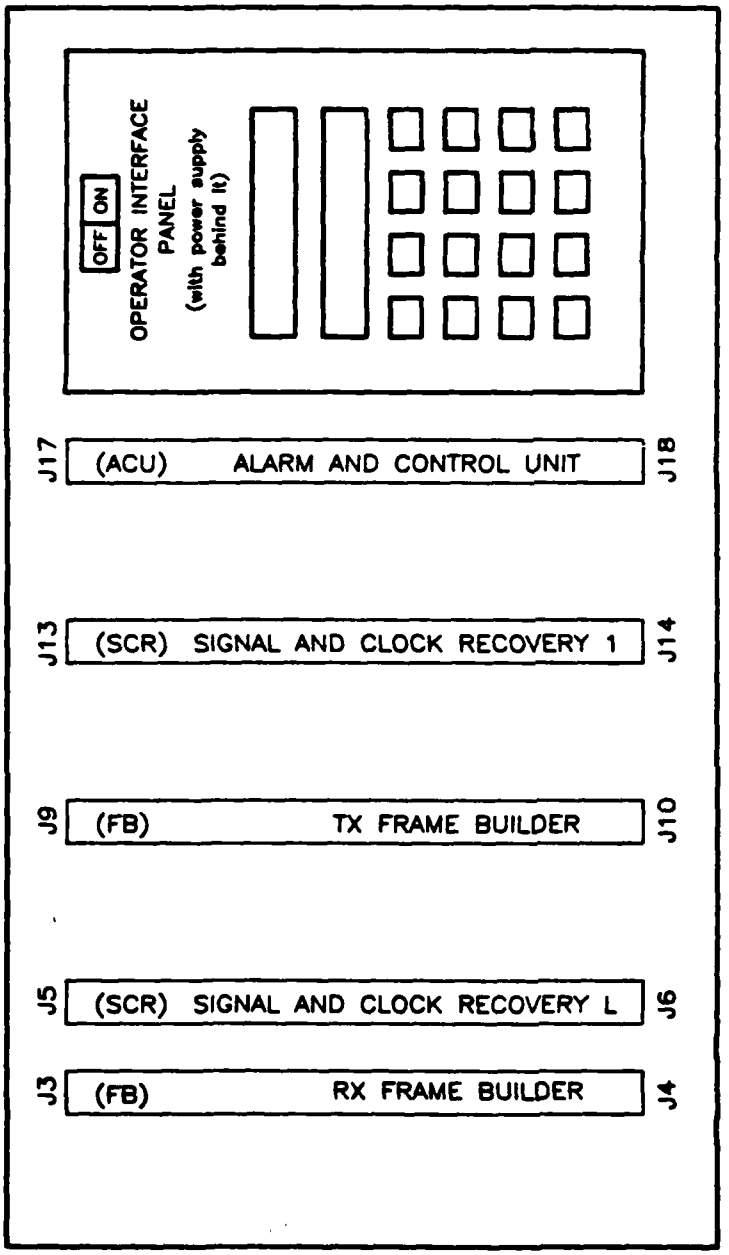


Figure 2-5. Rate Conversion/Format Conversion DCEM, Front Panel Removed

The Rate Conversion/Format Conversion DCEM can be upgraded at any time to a full-capability DCEM.

2.4 PHYSICAL CHARACTERISTICS

Height	12.25 inches
Width	19 inches
Depth	24 inches
Weight	52 pounds

2.5 POWER REQUIREMENT

Input Voltage	115 V ac ± 10% or 230 V ac ± 10% or -48 V dc ± 10%
Frequency Range on ac	47 to 420 Hz
Power	175 watts typical full capability

2.6 ENVIRONMENTAL CHARACTERISTICS

Operating Temperature	0° C to 40° C
Storage Temperature	-10° C to 80° C
Humidity	95% relative, max

2.7 RELIABILITY

Mean Time Between Failure (MTBF) > 3500 hours

Mean-Corrective-Maintenance-Time (MCT) < 12 minutes

2.8 ELECTROMAGNETIC INTERFERENCE

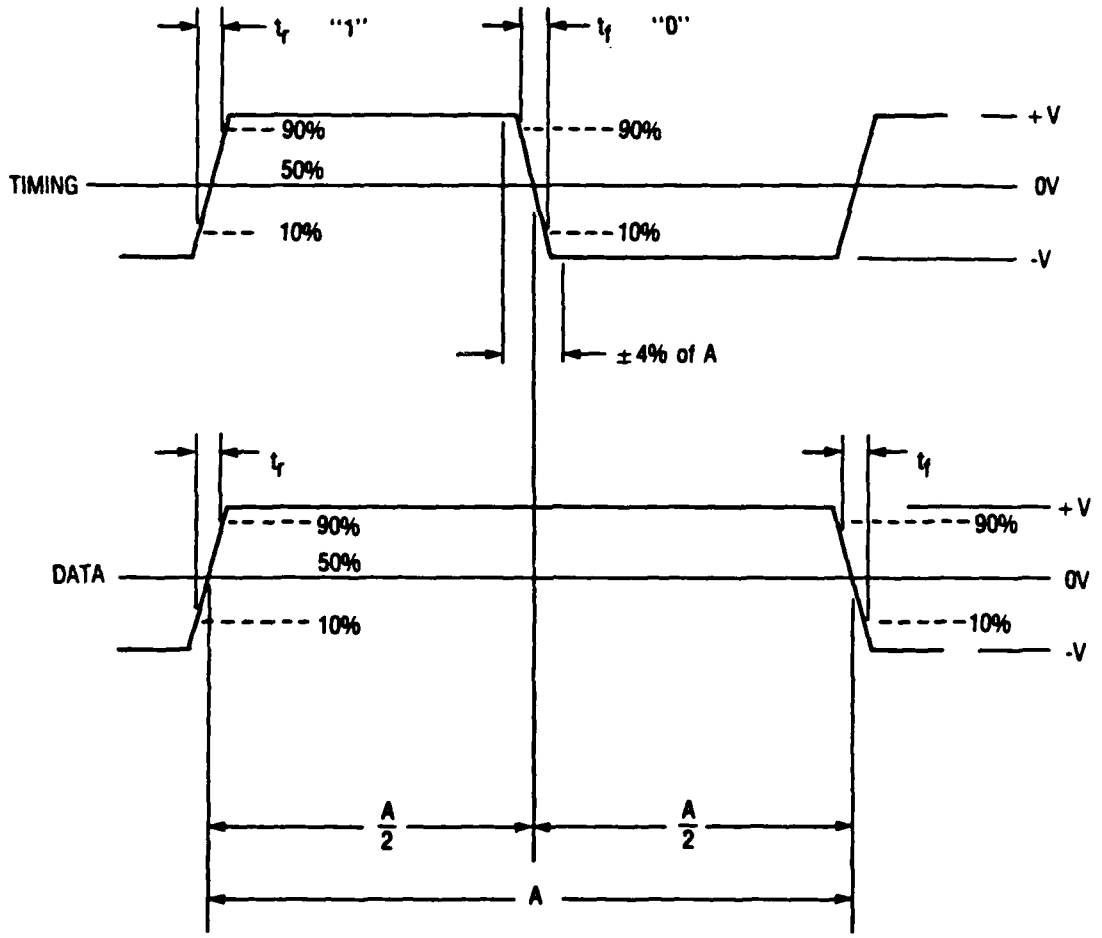
The DCEM was designed to the requirements of MIL-STD-461A notices 1, 2, and 3 and was tested to MIL-STD-462 (notice 2) test requirements. These tests consisted of Powerline Conducted Emissions Test Method CE03 (20 kHz to 50 MHz), Radiated Electric Field Emissions Test RE02 (14 kHz to 35 MHz), and Spike Susceptibility Test Method CS06.

2.9 INPUT AND OUTPUT SPECIFICATIONS

The DCEM has three input and three output ports capable of interfacing with the corresponding input or output ports of a PCM channel bank or repeatered transmission line. The DCEM is compatible with the following standards.

2.9.1 DCS 1.544 Mbps Standard

The DCEM conforms to the DCS 1.544 Mbps standard. The 1.544 Mbps data and timing interface characteristics are either balanced non-return-to-zero (NRZ) polar square wave data and associated clock as shown in Figure 2-6, or a bipolar signal as shown in Figure 2-7. See reference 2.



+V = 6V ± 1V, -V = -6V ± 1V (WHEN OPEN)
+V = 3V ± 0.5V, -V = -3V ±0.5V (WHEN TERMINATED WITH 78 OHM ±10% IMPEDANCE)
$t_r \leq 100$ ns, $t_f \leq 100$ ns
LOAD IMPEDANCE = 78 OHM ± 10%
OVERSHOOT ≤ 15%

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Figure 2-6. 1.544 Mbps Balanced NRZ Data and Timing Characteristics

LOCATION		DIGITAL DISTRIBUTION FRAME
BIT RATE		1.544 Mbps ± 50 ppm
PAIR(S) IN EACH DIRECTION OF TRANSMISSION		ONE SYMMETRIC PAIR
CODE		AMI[b]
TEST LOAD IMPEDANCE		100 OHMS RESISTIVE
NOMINAL PULSE SHAPE		RECTANGULAR
	POWER AT 772 kHz	+12 dBm TO +19 dBm
	POWER AT 1544 kHz	AT LEAST 25 dB BELOW THE POWER AT 772 kHz

a. THE PULSE MASK FOR 1ST ORDER DIGITAL INTERFACE IS SHOWN BELOW
b. THE SIGNAL LEVEL IS THE POWER LEVEL MEASURED IN A 3-kHz BANDWIDTH AT THE IN-JACK FOR AN "ALL ONES" PATTERN TRANSMITTED.

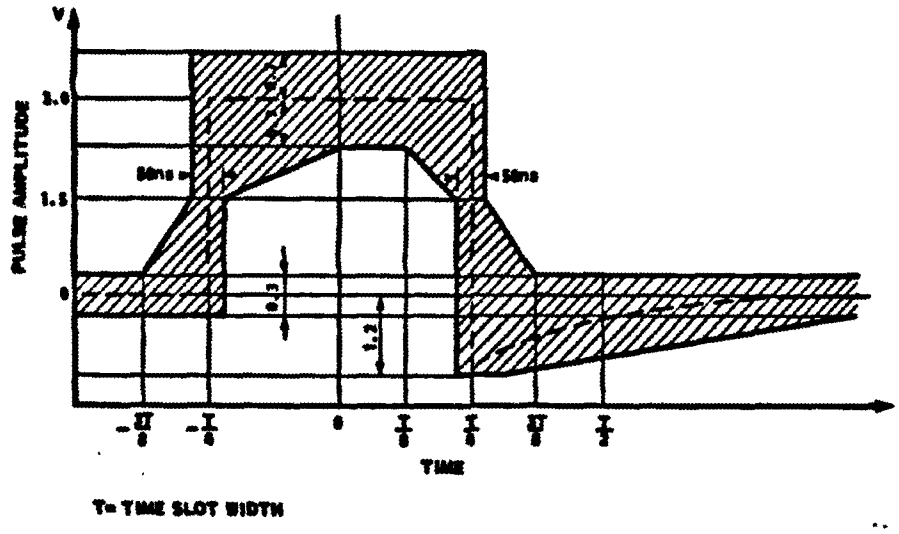

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Figure 2-7. Interface Characteristics for 1.544 Mbps Bipolar Signal

2.9.2 T1 1.544 Mbps Standard

The DCEM conforms to the North American standard T1 1.544 Mbps interface. See Figure 2-7 for the characteristics of the T1 interface; see reference 4.

2.9.3 CEPT 2.048 Mbps Standard

The DCEM conforms to the CEPT standard 2.048 Mbps interface. See Figure 2-8 for the characteristics of the CEPT standard; see reference 4.

2.9.4 DCS 3.088 Mbps Standard

The DCEM conforms to the DCS 3.088 Mbps balanced NRZ interface. This is shown in Figure 2-9; see reference 3.

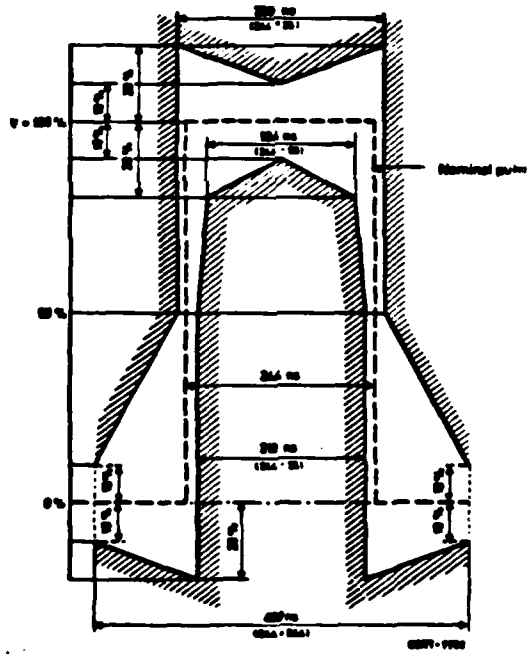
2.10 INTERFACE CABLING

Refer to Figure 2-10 for a view of the DCEM's five Input/Output ports used for operation and control. These are the console interface, alarm interface, PCM Terminal 1 port, PCM Terminal 2 port, and the PCM Repeatered Line Port. Connections to these five ports are made through standard 25-pin EIA D-type male connectors. There is also an error-rate (BER) monitor output through a BNC plug.

2.10.1 Console Interface Port

The console interface port, J2, is designed to operate with a standard RS-232C CRT terminal or printer. This is an optional connection, as an external console is not required for DCEM operation. The entire operation of the DCEM can be performed with the

Pulse shape (nominally rectangular)	All marks of a valid signal must conform with the mask irrespective of the sign. The value V corresponds to the nominal peak value	
Pair(s) in each direction	One coaxial pair (see Note below)	One symmetrical pair (see Note below)
Test load impedance	75 ohms resistive	120 ohms resistive
Nominal peak voltage of a mark (pulse)	2.37 V	3 V
Peak voltage of a space (no pulse)	0 ± 0.237 V	0 ± 0.3 V
Nominal pulse width	244 ns	
Ratio of the amplitudes of positive and negative pulses at the midpoint of a pulse width	0.95 to 1.05	
Ratio of the widths of positive and negative pulses at the nominal half amplitude	0.95 to 1.05	
Maximum jitter to be accepted by the equipments connected to the interface	Under study	



Note. – V corresponds to the nominal peak value.

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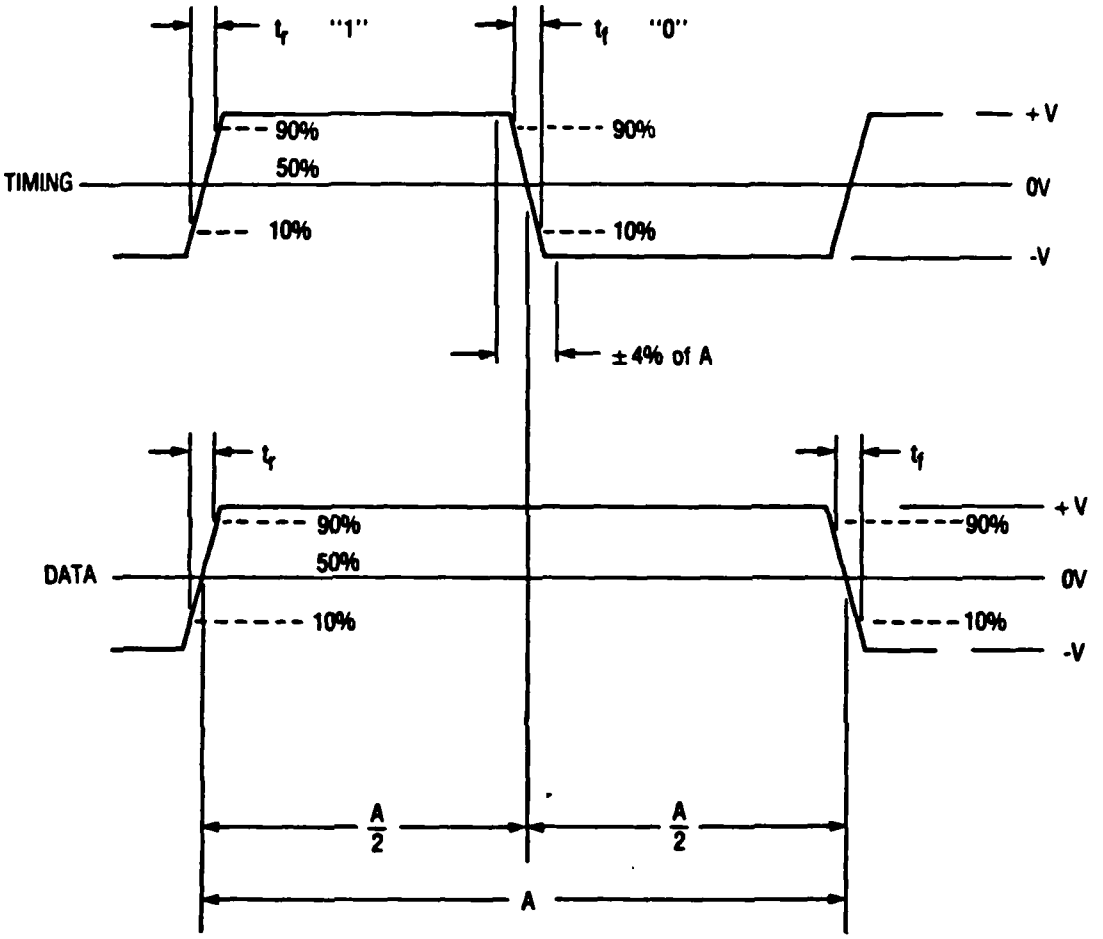
Figure 2-8. Interface Characteristics for 2.048 Mbps Signal



+V = 6V ± 1V, -V = -6V ± 1V (WHEN OPEN)
+V = 3V ± 0.5V, -V = -3V ±0.5V (WHEN TERMINATED WITH 78 OHM ±10% IMPEDANCE)
4 ns < t_r < 20 ns, 4 ns < t_f < 20 ns
LOAD IMPEDANCE = 78 OHM ± 10%
OVERSHOOT ≤ 15%

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Figure 2-9. 3.088 Mbps NRZ Data and Timing Characteristics

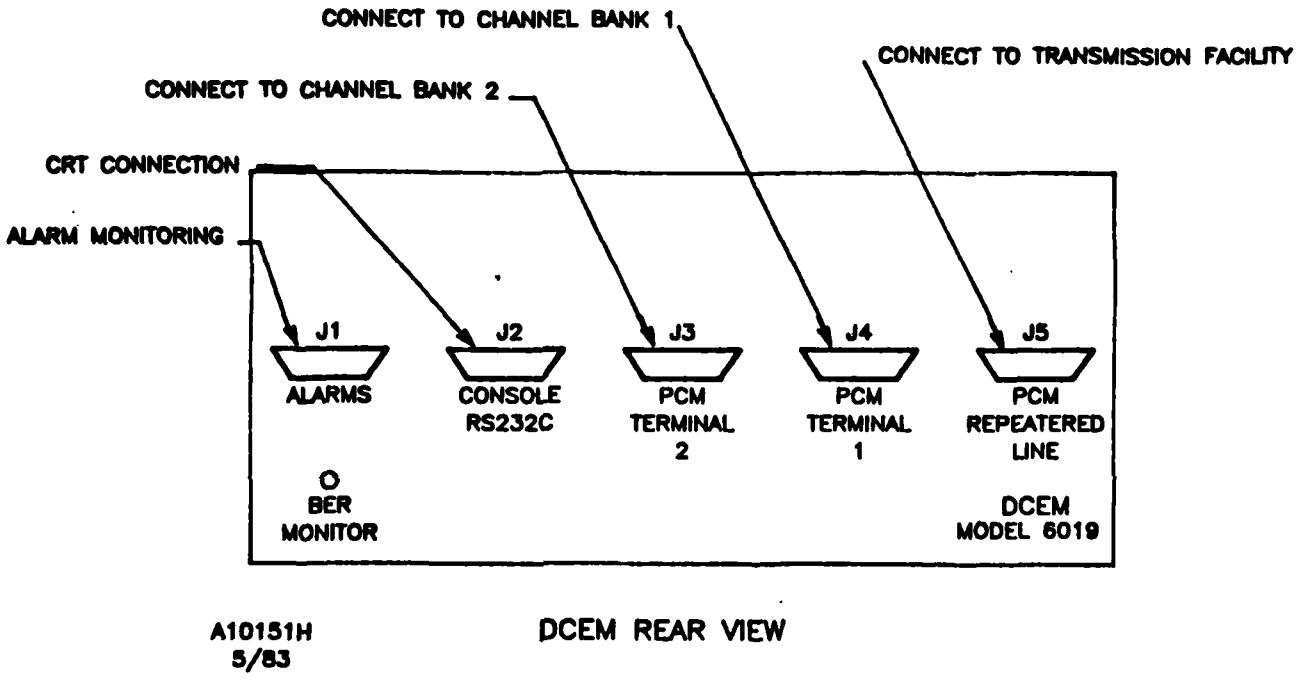


Figure 2-10. I/O Port Interface

keypad and LCD displays provided on the front panel. The operation may be more convenient, however, with a CRT connection.

The pinout of the Console Interface is shown in Table 2-1. The baud rate is selectable from 300 baud to 9600 baud by means of dip switches on the Alarm and Control Unit PC card. See Table 2-2 for these dip-switch settings.

2.10.2 Alarm Interface

The DCEM contains seven remote alarms, as listed below:

1) Loss of primary power
2) Loss of frame
3) Loss of output
4) Loss of input
5) Loopback
6) Carrier Group Alarm (CGA)
7) Fault alarm.

Each of these alarms contains a contact closure separated from ground and capable of carrying one ampere continuously. Normally open, normally close, and a common contact are provided. Table 2-3 provides the necessary pinout information to monitor these alarms.

2.10.3 PCM Ports

Each of the three PCM ports, labled PCM Terminal 1, PCM Terminal 2, and PCM Repeatered Line has the same pin connections as shown in Table 2-4. Each port has the capability of interfacing with bipolar or MIL-STD-188 type balanced NRZ clock and data lines, as

Table 2-1. Console Interface Connections (RS-232C)

Pin Number	Signal Name	Reference Direction on the DCEM
1	Ground, Chassis	
2	Transmit Data	In
3	Receive Data	Out
4	Request to Send	In
5	Clear to Send	Out
6	Data Set Ready	Out
7	Ground, Signal	
8	Ground	
9	No Connection	
10	No Connection	
11	No Connection	
12	No Connection	
13	Ground	
14	No Connection	
15	No Connection	
16	No Connection	
17	No Connection	
18	No Connection	
19	No Connection	
20	Data Terminal Ready	In
21	No Connection	
22	No Connection	
23	No Connection	
24	No Connection	
25	No Connection	

Table 2-2. Console Baud Rate Dip-Switch Settings

BAUD RATE	SETTING S3	S2	S1	S0
300	1	1	0	1
600	0	1	1	0
1200	1	0	1	1
1800	1	0	1	0
2400	0	1	1	1
4800	1	0	0	1
9600	1	0	0	0

Table 2-3. Remote Alarms Connections

Pin Number	Signal Name
1	No Connect
2	Power Loss C.
3	Power Loss N.C.
4	Power Loss N.O.
5	Input Framing Loss C.
6	Input Framing Loss N.C.
7	Input Framing Loss N.O.
8	Loopback Alarm C.
9	Loopback Alarm N.C.
10	Loopback Alarm N.O.
11	Input Signal Loss C.
12	Input Signal Loss N.C.
13	Input Signal Loss N.O.
14	Output Signal Loss N.O.
15	$\overline{\text{Frame Search Inhibit}}$
16	$\overline{\text{Loopback Command}}$
17	Fault Alarm C.
18	Fault Alarm N.C.
19	Fault Alarm N.O.
20	Input Framing Loss N.O.
21	Carrier Group Alarm C.
22	Carrier Group Alarm N.C.
23	Carrier Group Alarm N.O.
24	Output Signal Loss C.
25	Output Signal Loss N.C.

Table 2-4. PCM Port Connections

Pin Number	Signal Name
1	NRZ Clock Out
2	NRZ Clock Input
3	NRZ Data Out
4	NRZ Data Input
5	Bipolar Out
6	Bipolar Input
7	External Clock
8	External Clock
9	No Connect
10	Ground
11	Ground
12	Ground
13	Ground
14	NRZ Clock Out
15	NRZ Clock Input
16	NRZ Data Out
17	NRZ Data Input
18	Bipolar Out
19	Bipolar Input
20	External Clock
21	No Connect
22	No Connect
23	Ground
24	Ground
25	Ground

discussed in Subsection 2.9 and can be programmed independently of the other two ports.

2.10.4 BER Monitor

The BER Monitor output produces a pulse at the output such that it has a pulse rate of approximately 8,000 times the bit error rate. The source impedance is 75 ohm ±10%, unbalanced, and the signal is a 1 volt ±10% square pulse.

SECTION 3.0
FUNCTIONAL DESCRIPTION

3.1 FUNCTIONS PERFORMED

The DCEM has three general operational configurations. The first is the speech compression configurations A, B, C and I. The second is the rate conversion configurations D and E, and the third is the format conversion configurations F, G, and H. Each of these configurations is discussed in detail below.

3.2 SPEECH COMPRESSION

In the compression modes, the number of input channels to the DCEM from the channel banks cannot be transmitted with the number of bits available on the transmission facility. In order to achieve transmission of all the channels, the DSI/ADPCM concept is used.

This concept consists of the following:

- An activity detector so that only active channels are allocated bits in the output frame
- Bit dropping, which allows graceful degradation during periods of heavy loading
- ADPCM rather than PCM transmission, to regain S/N_q lost by bit dropping
- Bypassing of data channels around the bit dropping and ADPCM.

3.2.1 Compression Algorithms

This subsection discusses the following aspects of the compression system used on the DCEM: bit assignment, activity detection, data channels, ADPCM, transmission of channel assignment information, and overload protection. In general mode A will be discussed; however, the other compression modes are similar.

3.2.1.1 Bit Assignment

A compression frame in the DCEM is divided into the following fields. (See Figure 3-1.)

- Framing bits - Similar to those used in the D3 channel banks.

- Signaling bits - In the D3 channel bank format, where signaling bits are sent in place of PCM sample LSBs, signaling bits are stripped out by the DCEM and grouped into a separate 8-bit field in the frame. In the CEPT format signaling bits are already grouped in a separate 8-bit field, so this field is passed in the compression frame unmodified.

- Channel assignment information - Provides information on the dynamic assignment of the remaining bits in the frame.

- Data channel bits - Each data channel, whether preassigned as data (digital data) or detected as data (voiceband data), is assigned 8 bits in the frame.

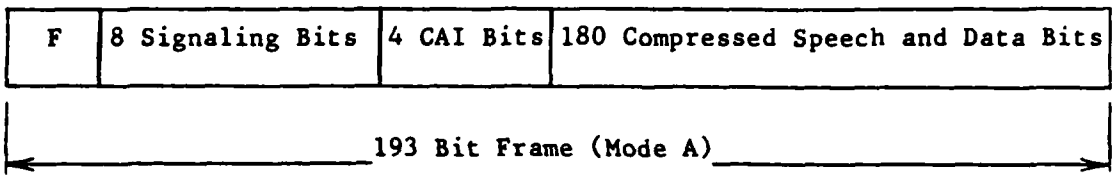
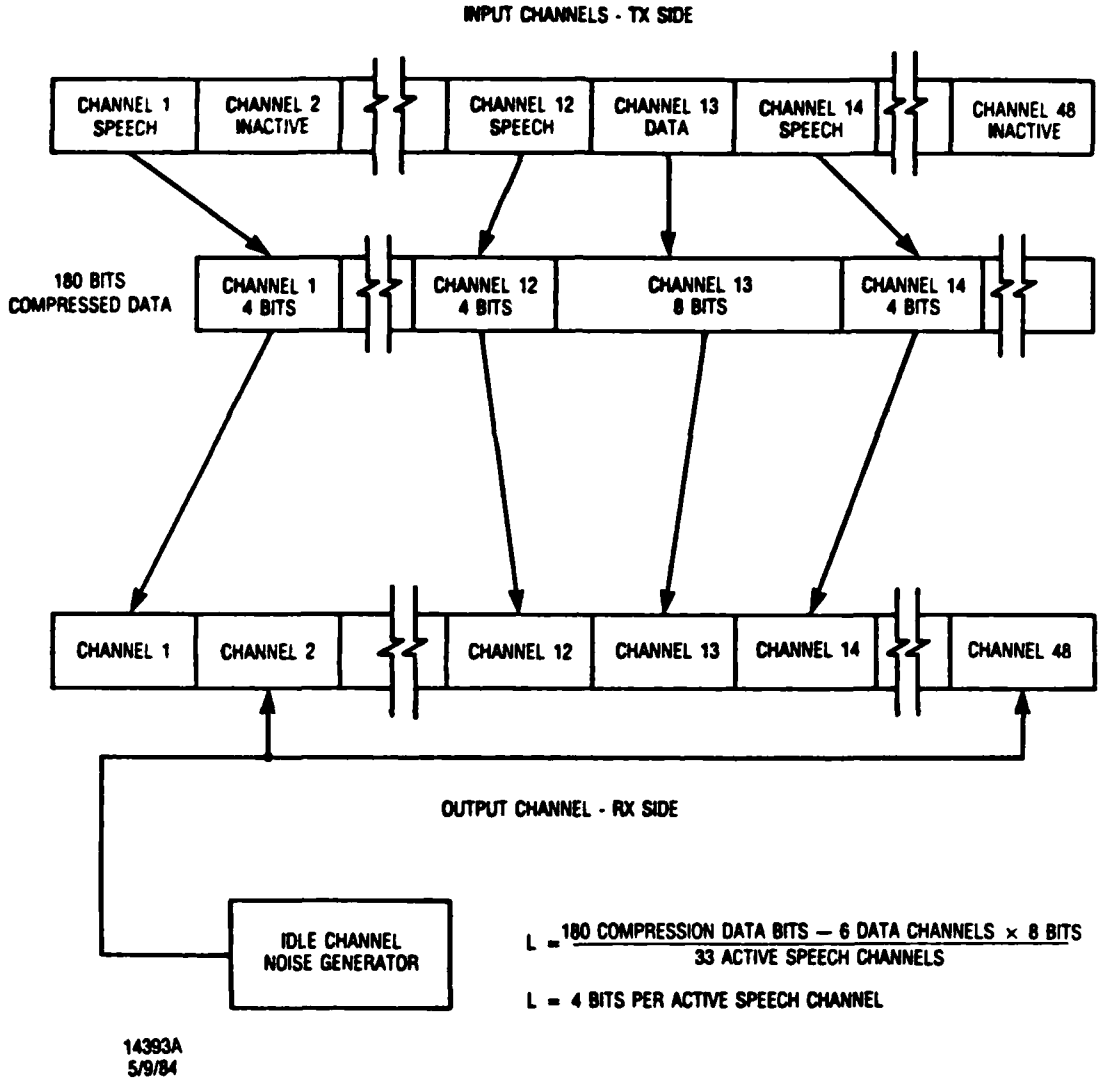


Figure 3-1. Compression Frame - Mode A

- Speech channel bits - The remaining bits in the frame are divided among the the active speech channels. This determines the ADPCM word length (L), which varies from L = 8 to L = 3.

On the DCEM, compression is achieved by using DSI with ADPCM. Using DSI implies that only active channels require bandwidth in the output frame. Since the output frame has only 180 bits (mode A) available for up to 48 8-bit channels, channels have to be compressed further. In order to make room for all of these channels the number of bits per speech channel is reduced by using ADPCM while each data channels maintains 8 bits per channel. The process of combining the compress speech channels and data channels into the compression frame is shown in Figure 3-2.

One further consideration applies when the number of digital and voiceband data channels become relatively large. For each additional data channel, there is an 8-bit decrease in the number bits available for speech channels. Since the 8 bits that were lost could have been shared by more than one speech channel, at some point as the number of data channels increase there would be no bits remaining for speech channels. To alleviate this problem the DCEM has built-in overload protection which limits the number of data channels allowed. This is a user programmable limit for up to 16 data channels maximum. In addition to ensure that the quality of speech remains high, the value of L is not allowed to fall below 3. If the number of active channels increase so that 3 bits are not available for each speech channel, front end clipping is introduced on newly active channels until 3 bits are available. More details of the overload protection used on the DCEM is discussed in Subsection 3.2.1.6.



THE ABOVE FIGURE SHOWS HOW CHANNELS ARE COMPRESSED INTO THE 180 BIT COMPRESSION FRAME ON THE TX SIDE AND EXPANDED ON THE RECEIVE SIDE.

Figure 3-2. Compression/Expansion Algorithm

3.2.1.2 Activity Detector

The performance in compression modes is heavily dependent on reliable and accurate detection of speech activity on a channel. Since inactive speech channels are not allocated bits in the output frame format, it is important to identify precisely when the speech burst exists. If the detection scheme is slow in detecting activity, front end clipping will result. If it is too sensitive, noise spikes will trigger the switch and use unnecessary bits in the output format, thereby degrading the performance of the other active speech channels. The features of the DCEM activity detector are as follows:

- Adaptive level threshold set to the idle channel noise level
- Delay to prevent front end clipping
- Hangover to prevent end of burst clipping
- Resistance to triggering on echoes.

The activity detector algorithm used on the DCEM is shown in Figure 3-3.

3.2.1.2.1 Adaptive Level Threshold

The activity detector uses three thresholds to determine the presence of activity, TA, TN, TM.

TN is the noise threshold used to determine the level of the background noise. It is allowed to adjust the entire time that

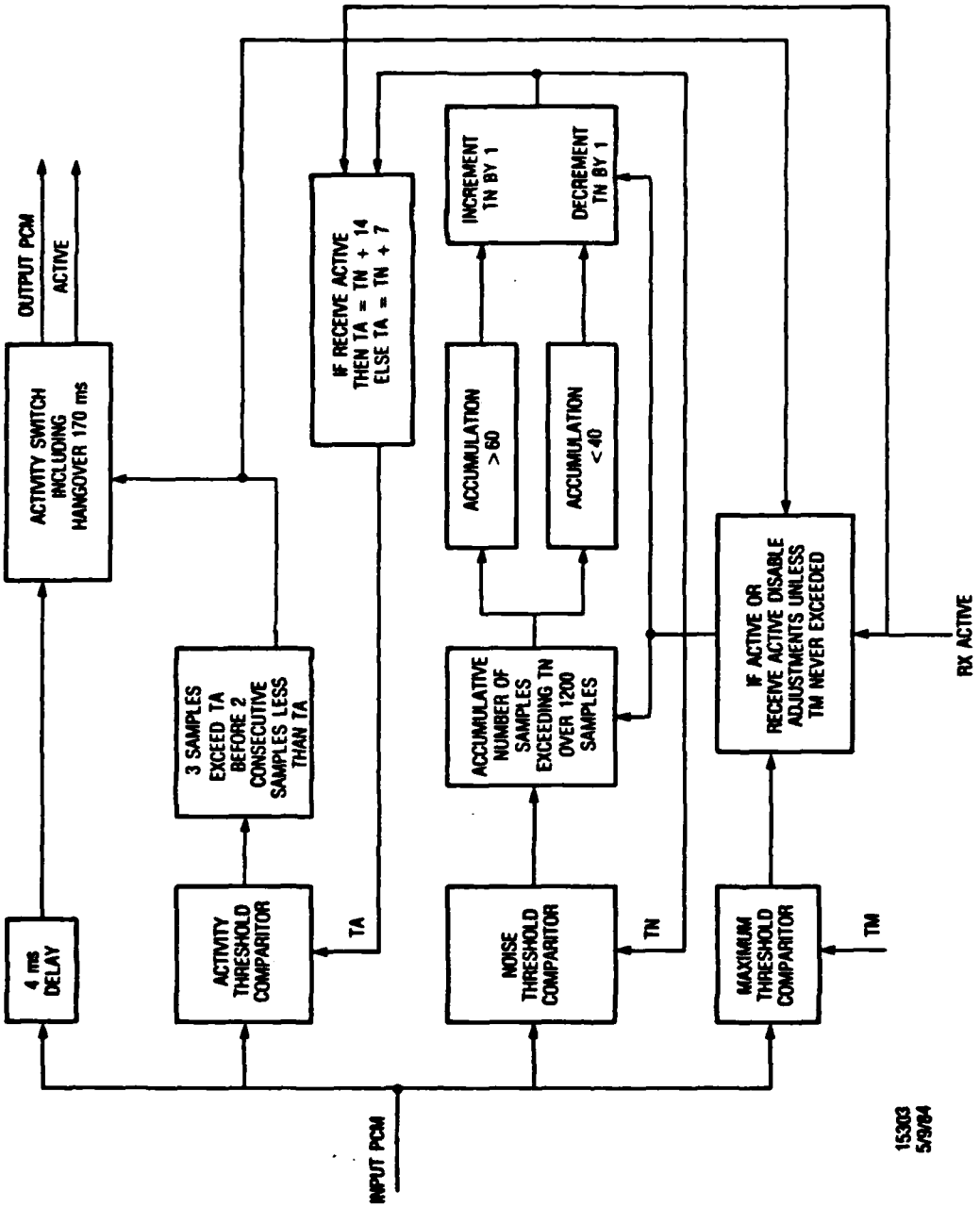


Figure 3-3. Activity Detector Flow Diagram

activity is not present. Once the level of the idle channel noise has been determined, activity is detected using TA, which is set seven levels above TN. If three samples exceed TA before two consecutive samples are less than TA, then activity is considered present. This method is used to maintain a constant level above the noise for triggering activity regardless of the frequency of the signal.

The third threshold TM is used to determine when adjustment should be made. This is a fixed threshold set high enough such that if the level of the input signal exceeds TM, then activity should be considered present. It is also set low enough so that low level speech should exceed TM while typical idle channel noise will not. Once a signal goes active, TN adjustment is disabled. This is done to prevent TN from adjusting to the speech level and allowing the channel to become inactive. If a channel goes active and threshold adjustment is disabled, it is expected that TM will always be exceeded. If TM is not exceeded for 80 sec, however, TN adjustment is allowed. This will prevent a lock-up state.

3.2.1.2.2 Delay

Four millisec of delay is introduced on each channel. This allows the activity detector time to detect the presence of activity without clipping off the front end of a speech burst.

3.2.1.2.3 Hangover

The DCEM uses a 170 millisec hangover after the end of a speech burst to prevent end of burst clipping.

3.2.1.2.4 Echo Control

Echoes can cause the threshold TN to be adjusted incorrectly or falsely trigger activity on a channel. To prevent this from affecting the activity dectector performance, TN adjustment is disabled and TA is set at 14 steps above TN whenever the receive channel is on.

3.2.1.3 Data Channels

There are two types of data channels, digital data channels and voice band modem channels. Each of these data channels types is allocated 8 bits per sample. Digital data channels are set through operator commands and voice band modem channels are detected and assigned 8 bits per sample.

Features of the modem data detection algorithm are as follows:

- Activiated by the activity detector - during periods of inactivity no decisions are made.
- Fast discrimination time of less than 150 millisec.
- Dynamically changes the decision as the signal characteristics change.
- Memory - Decisions are initialized to previous active burst values until a new decision can be made.

Detection of modem or voice band data channels is accomplished by taking advantage of the fact that voice band data

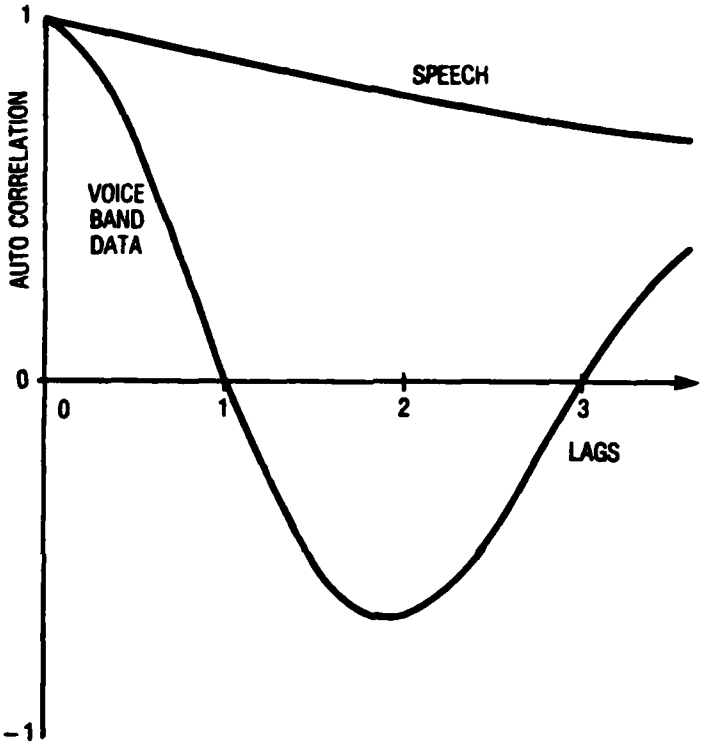


Figure 3-4. Speech Data Discriminator

signals differ significantly from speech signals. The DCEM uses the autocorrelation of adjacent sample to distinguish between data and speech. The autocorrelation of adjacent samples drops off very rapidly for data while speech changes much slower. Figure 3-4 shows a typical plot of the autocorrelation for speech and data signals. The DCEM calculates the autocorrelation at 1 and 2 lags (R1 and R2) for each input channel and uses the decision grid shown in Figure 3-5 to discriminate between speech and data signals. In addition hysteresis is used on decisions to prevent small perturbations in the signal from causing a state change. This technique has been shown to work well with speech signals and data signals as long as most of the energy is above 1000 Hz (which is typical of most all modems). For modems with power less than 1000 Hz, the channel will pass through the ADPCM algorithm. However, ADPCM works very well with signals of less than 1000 Hz and typically will pass error free through the DCEM (if the BER = 0 on the transmission facility) even under heavy loading.

3.2.1.4 ADPCM

The DCEM incorporates ADPCM instead of PCM processing during heavy loading. This is a technique by which the difference between the PCM input and a predicted PCM value (predicted in the ADPCM algorithm) is transmitted. This allows a smaller number of bits to be transmitted for each PCM sample while the signal to quanitzing noise ratio (S/N_q) is maintained at high levels. The ADPCM algorithm features are as follows:

- All available speech channel bits in the output frame are used to maximize speech quality.

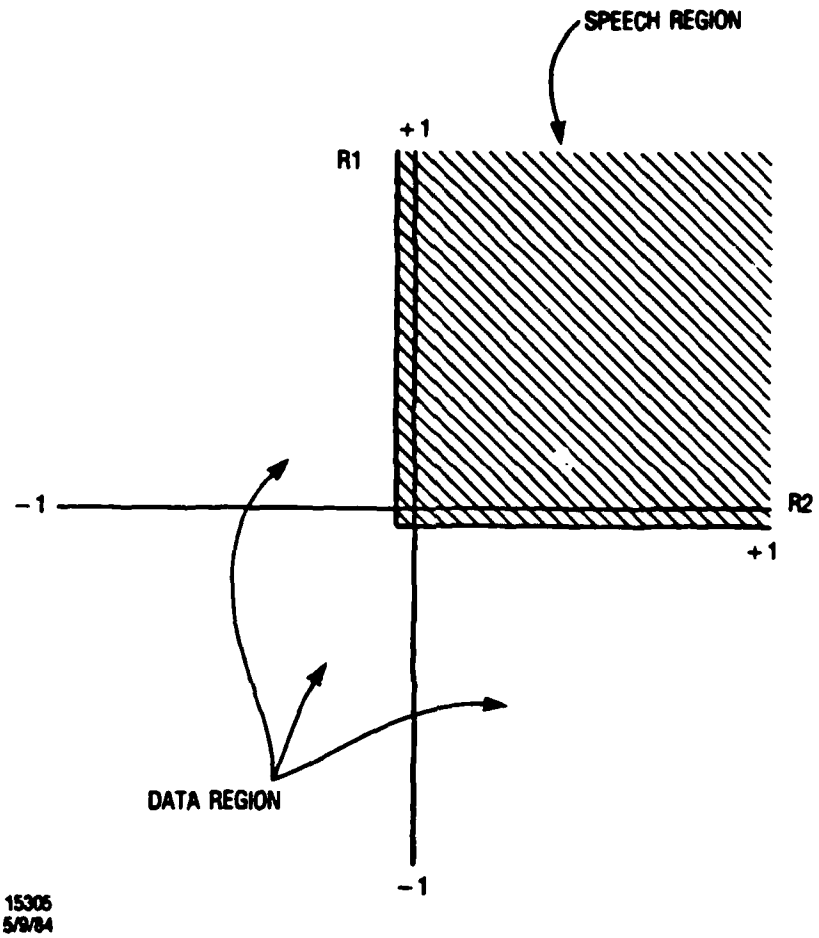


Figure 3-5. Speech/Data Decision Grid

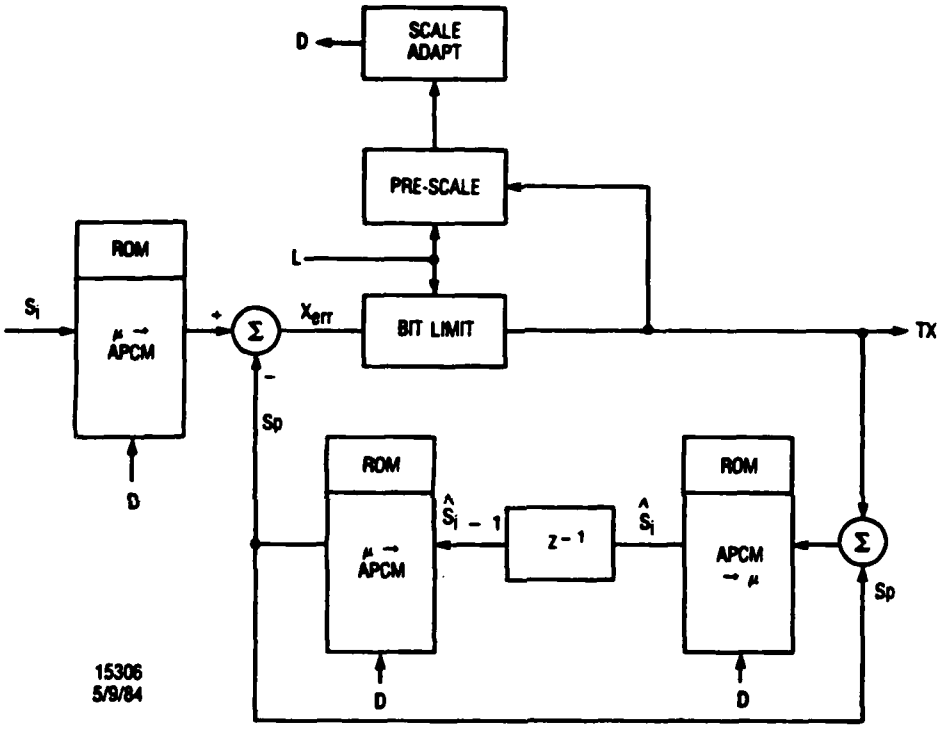


Figure 3-6. ADPCM Block Diagram

- Whenever 8 bits are assigned to a speech channel, PCM is used instead of ADPCM.

Figure 3-6 shows the DCEM ADPCM block diagram.

ADPCM is a well known technique for processing speech. There are many references which explain in detail how the algorithm works. In this report we will not repeat the details of the algorithm but will provide information on the performance of the ADPCM used on the DCEM.

The way in which an objective evaluation was made of the ADPCM algorithm was through signal-to-quantizing noise ratio (S/N_q) measurements. Figures 3-7 and 3-8 show the measured DCEM S/N_q for a 1004 Hz tone with C-message weighting. Another important ADPCM measurement is the effects of bit errors on the S/N_q. Figures 3-9 and 3-10 shows a plot of the S/N_q at various bit error rates for a 1004 Hz tone.

3.2.1.5 Transmission of Channel Assignment Information

The channel assignment information (CAI) indicates the possible state of each channel (inactive, speech or data). The CAI is generated on the transmit side, to indicate how the compressed frame is put together and sent to the receive side, on the receive side the compressed data is expanded back to 8-bit PCM time slots for each channel of channel banks. This compression/expansion process is shown in Figure 3-2. If transmission errors are introduced in the CAI, the receive side will not be able to correctly expand the received data. Therefore, error free reception of the CAI is important to the performance of the DCEM. Below is an analysis of the effects of CAI transmission errors on the DCEM.

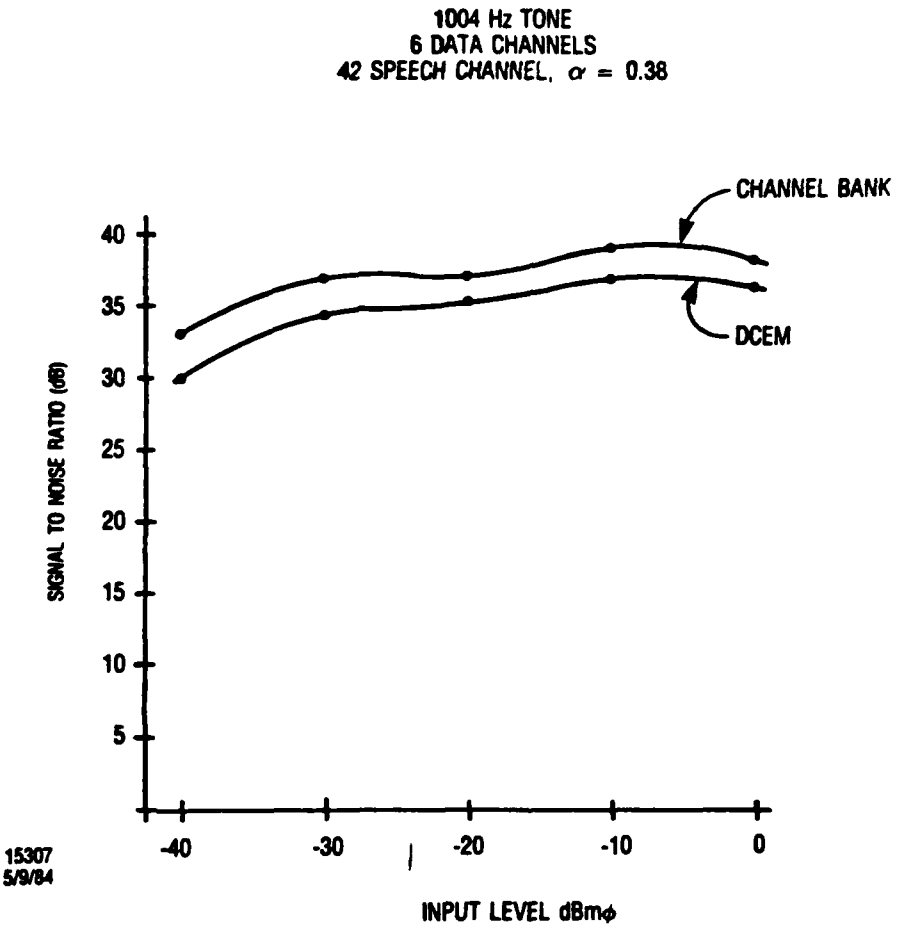


Figure 3-7. S/N_q for 1004 Hz Tone, Fully Loaded

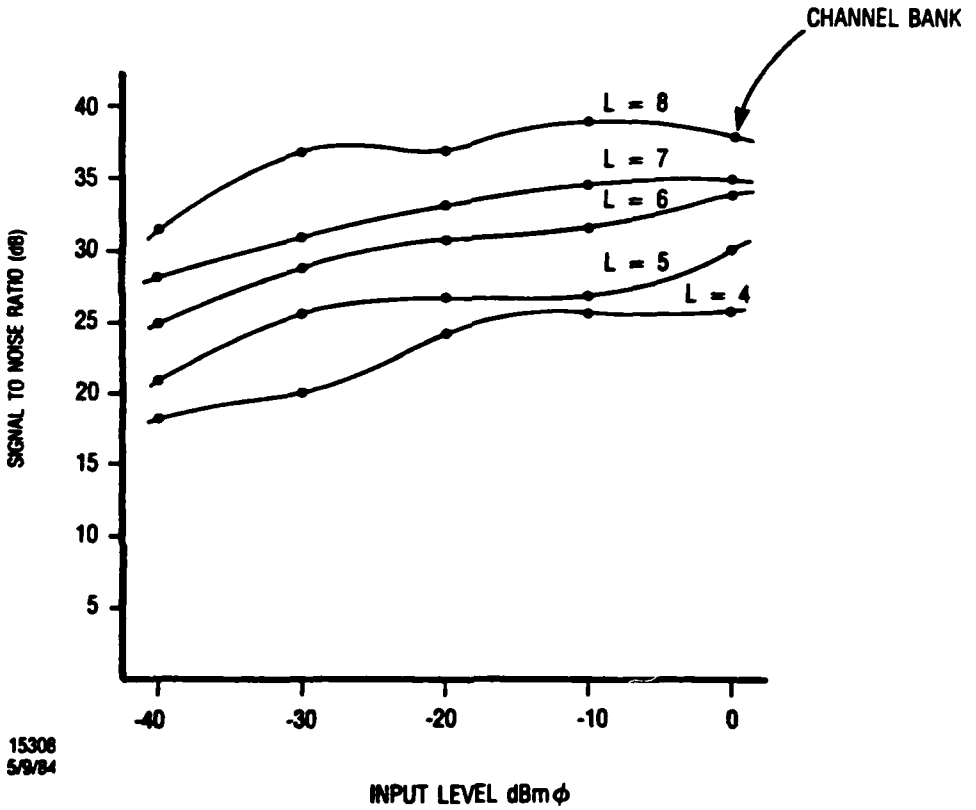


Figure 3-8. S/N_q for 1004 Hz Tone, Measured

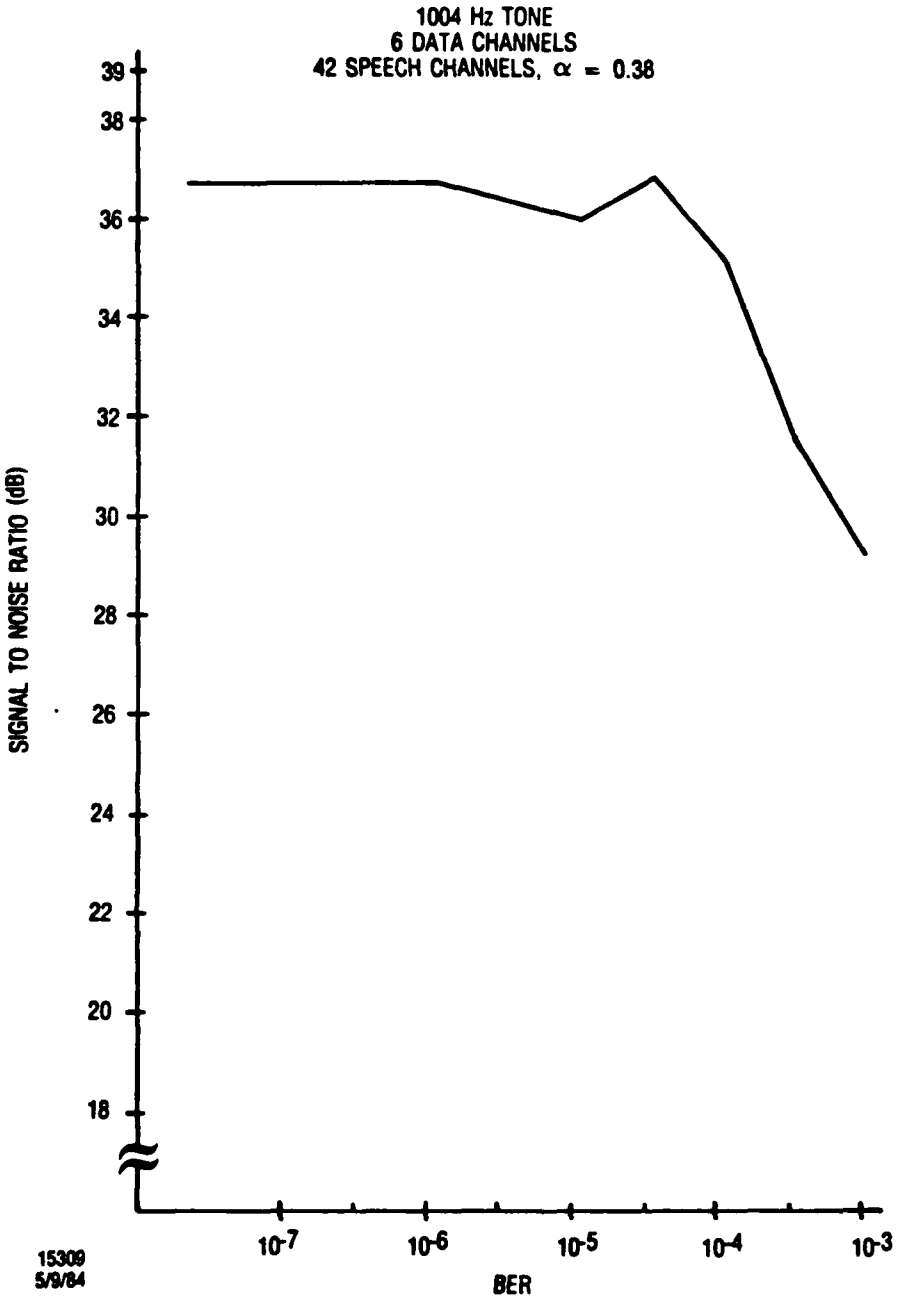


Figure 3-9. S/N_q vs Bit Error Rate (BER)

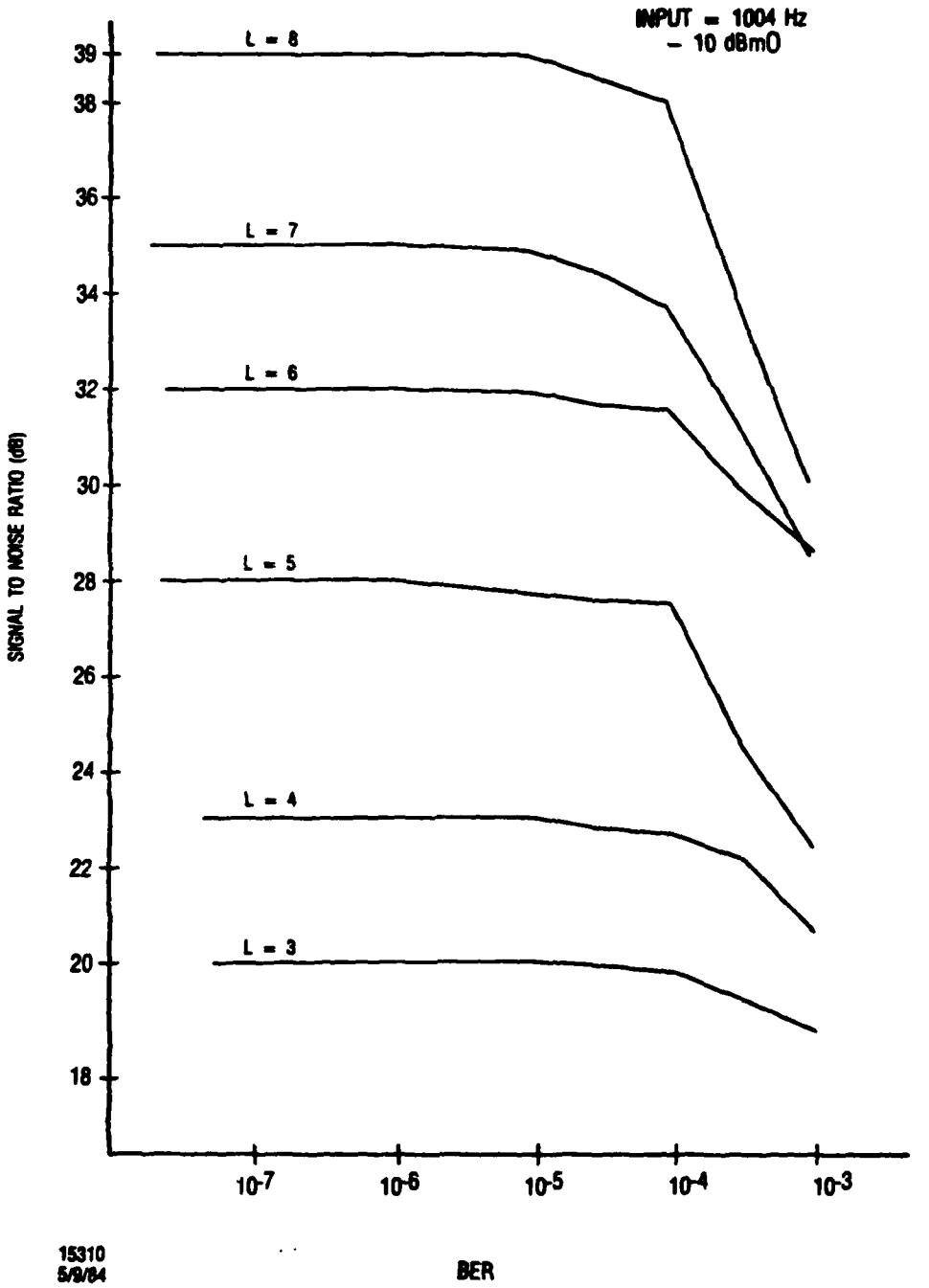
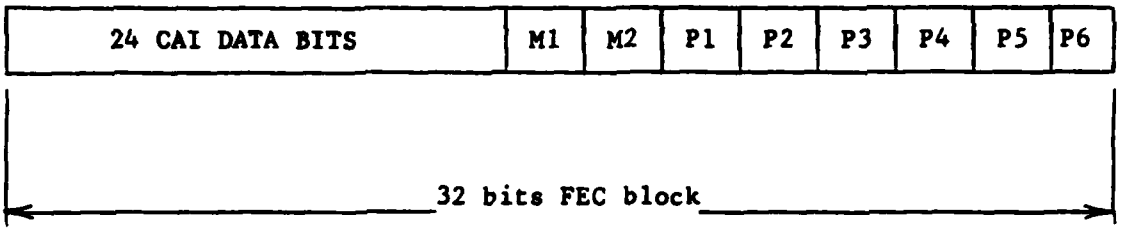


Figure 3-10. S/N_q vs. Bit Error Rate

3.2.1.5.1 Description of CAI Transmission

Before proceeding with the analysis we must first determine how the CAI is transmitted and gain some sort of intuitive feel for how corruption of CAI affects the user. In order to minimize the number of errors in the CAI, FEC has been used on the CAI bits. The FEC codec uses a modified Hamming code that is capable of correcting single errors in the CAI and detecting double errors. The code requires 26 data bits and 6 parity check bits per FEC block. Each FEC block contains 24 CAI bits, 2 microprocessor channel bits along with six parity check bits as shown in Figure 3-11. In each DCEM frame there are four consecutive bits dedicated for the transmission of the FEC block. Therefore, it takes eight frames to transmit each CAI block of 32 bits. As will be shown later it takes 6 millisec or 48 frames to update the CAI bits once for all 48 channels.

If during the transmission of the CAI several bit errors are introducted into one of the blocks, the FEC codec will not be able to correct the errors and the CAI will be corrupted. Since it takes 6 millisec to update the CAI, the receiver will incorrectly expand the received compressed data for 6 millisec. Corrupted CAI introduces two kinds of expansion errors, both will typically happen for each CAI corruption. The first is not knowing which of the three possible states a channel is in. As an example, suppose channel 12 is an active speech channel and channel 13 is a data channel as shown in Figure 3-12. Because of corrupt CAI, assume channel 12 is changed to inactive. This will sound like a 6 millisec speech clip on channel 12 which will not be too objectionable. However, since the receiver thinks this channel is inactive, the L bits transmitted for channel 12 were never sent to channel 12 as is normally done, see Figure 3-2.

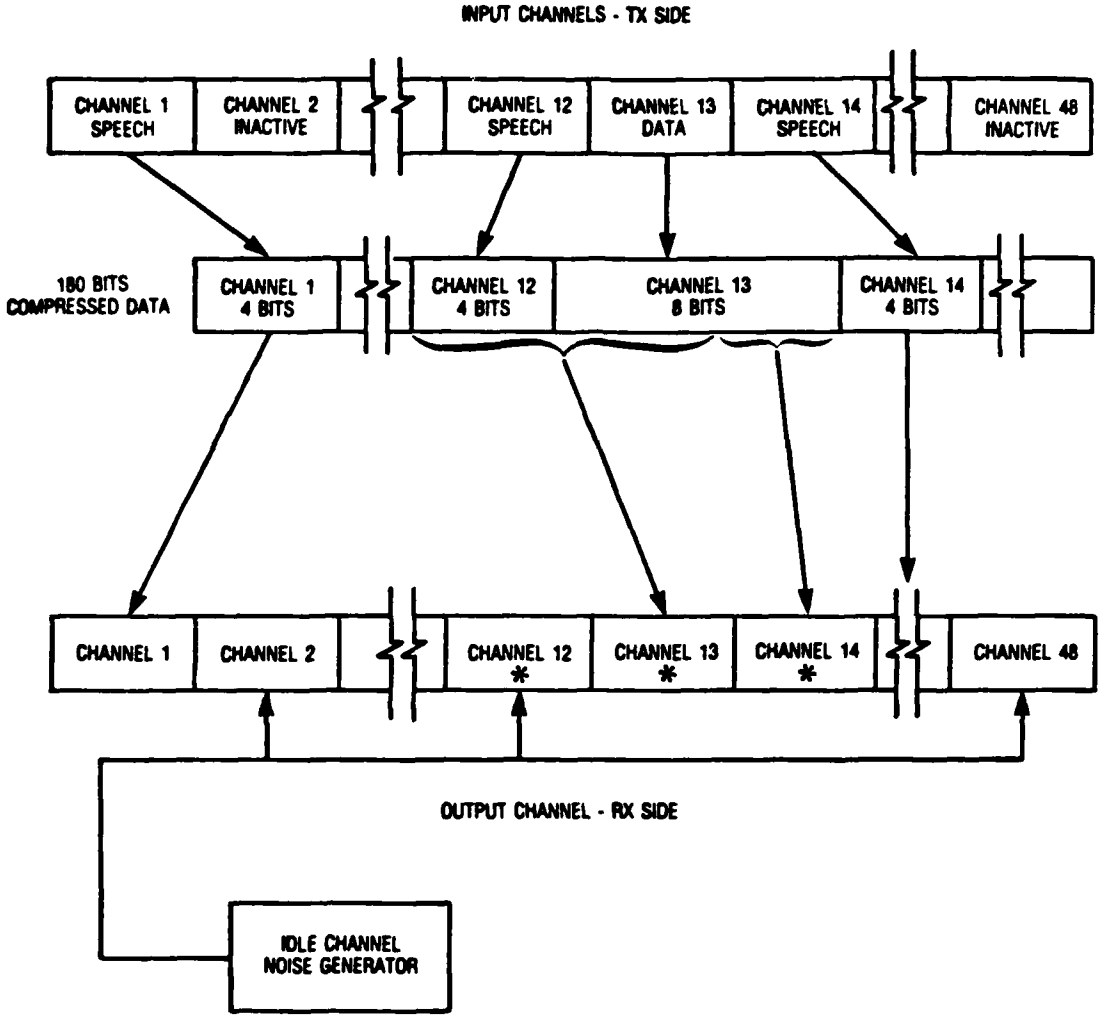


where:

M1, M2 are microprocessor channel bits

P1-P6 are parity check bits.

Figure 3-11. FEC Block



* INCORRECT ASSIGNMENT OF COMPRESSED DATA BITS AS A RESULT OF CORRUPTED CAI

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Figure 3-12. Compression/Expansion Algorithm with CAI Errors

When channel 13 is being processed it will get 8 bits but the first L bits will be channel 12's bits. This happens because channel 12's bits were never removed from the compressed data frame as a result of the CAI corruption. This can be more clearly seen in Figure 3-12. Not only is channel 13 receiving the incorrect bits, there is a good chance that all active channels following channel 13 will also receive the wrong bits. Therefore, an error on one channel can affect many more. It is also important to note that for every CAI corruption, it does not automatically mean that all 48 channels are affected. This depends on which CAI bits are corrupted.

The other type of expansion error is in determining the value of L (the number of bits per speech channel). If the receiver does not know the state of the channels, it cannot calculate the correct number of bits to assign to each speech channel. Therefore, in assigning bits to a speech channel it would not remove the correct number of bits from the compressed frame. This would disrupt that channel and all channels which are processed afterward.

In all cases corrupted CAI may not have a large subjective effect. For example, if we have 46 speech users and 2 data users with an activity factor of 0.38, then the following would apply. Of the 46 speech users typically 29 would be inactive and would be receiving idle channel noise. Therefore, most of the speech users would not hear any effect of the CAI errors because they are listening to idle channel noise. Of the 17 active speech users, they will hear a 6 millisec noise burst. This is short enough where it would sound much like a typical noise pop caused by bit errors. The data users would have the most noticeable affect. They would get 32 consecutive bytes of data in error with a 50% average error rate. If the system is not heavily loaded, there would be even less of an effect.

3.2.1.5.2 Performance of the CAI FEC Codec

Now we will proceed to analyze the DCEM in a transmission environment in order to determine how often the CAI will be corrupted. Recall that the CAI FEC codec will correct single bit errors and detect double bit errors. The advantage of single error correction is evident, however, the advantage of double error detection must be shown. Whenever a double error is detected by the CAI FEC codec it is assumed that the previous CAI is more likely to be correct than the received CAI with two possible errors. Therefore, if a double error is detected, the previous CAI data is used and no update is performed. In order to demonstrate the advantage of using the previous CAI, we will make several assumptions as listed below.

Assumptions:

1) There are 48 offhook speech users (48 seized channels)

2) The activity factor $\alpha = 0.38$

3) The mean speech spurt length

   $\gamma = 12000$ samples (1.5 seconds)

4) From assumptions 2 and 3 the mean silent spurt length

   $= \frac{\gamma}{\alpha} - \gamma = 19579$ samples (2.4 seconds)

5) The mean speech spurt length is Gaussian distributed.

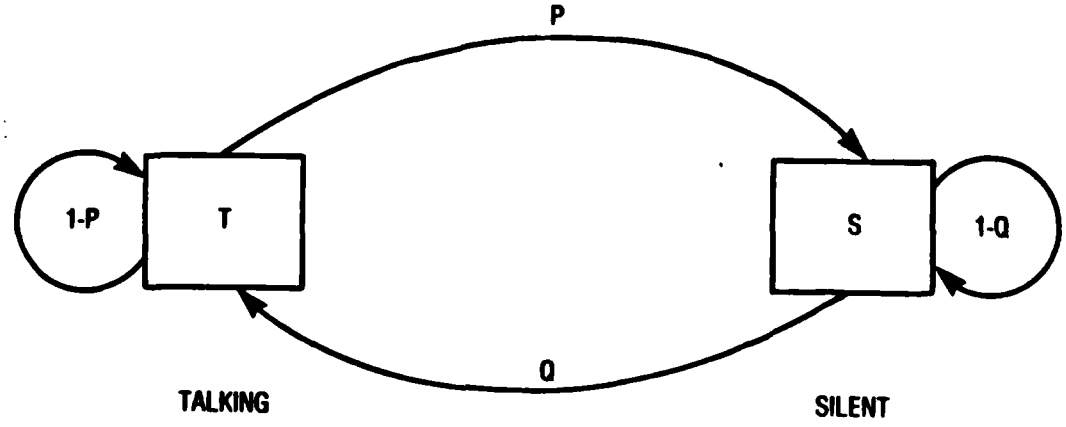

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Figure 3-13. Model of a Phone Conversation

The assumptions represent worst case since most of the time all 48 channels are not seized and the CAI is more static. The more static the CAI is, the more it decreases the chance of having corrupted CAI as a result of bit errors since previous CAI is used whenever two CAI errors are present.

Using the above assumptions we can model a typical phone conversation as shown in Figure 3-13. With this model there are two states, talking (T) and silent (S). If the probability of changing from T to S is P, then the probability of continuing to talk if you were talking is 1-P. Likewise, if the probability of changing from S to T is Q, then the probability of remaining silent is 1-Q. Given that the mean number of samples in the T state is 12000, then the probability of leaving T is $P = \frac{1}{12000}$ and likewise $Q = \frac{1}{19597}$. Knowing these probabilities we can calculate the probability that a channel will not change states. This is

$$P(\text{no change in state for 1 channel}) = (1-P)P(T)+(1-Q)P(S)$$

where

1) P(T) is the probability of being in state T, which = α.

2) P(S) is the probability of being in state S, which = $1-\alpha$.

$$P(\text{no change in state for 1 channel}) = (1-P)\alpha + (1-Q)(1-\alpha)$$

$$= \left(1 - \frac{1}{12000}\right)(0.38) + \left(1 - \frac{1}{19579}\right)(0.62)$$

$$= .99993667$$

The probability of no change of state on a channel in the 6 millisec between sampling by the CAI algorithm is the probability of no change in 48 consecutive samples.

P (no change in 48 samples for 1 channel)

$= P(\text{no change in state for 1 channel})^{48}$

$= (.99993667)^{48}$

$= .997$

Which means that in 6 millisec 99.7% of the time a channel will not change state.

Since each FEC block contains CAI for 24 channels the probability of 24 independent channels remaining in the same state for 6 millisec is

P (no change in 48 samples for 24 channels)

$= P(\text{no change in 48 samples for 1 channel})^{24}$

$= (.997)^{24}$

$= .93$

Which means that on any given FEC block, 93% of the time the CAI will be the same between each 6 millisec update. As a result, if a double error in the CAI is detected and the previous CAI is used, it will be correct 93% of the time. Therefore, double error detection is very useful!

3.2.1.5.3 Effects of Transmission Errors

Now that we have determined how the DCEM functions, we can begin looking at what happens in the presence of bit errors. In our analysis we are assuming errors are randomly distributed.

In this system the CAI will remain uncorrupted if one or less errors is in the FEC block of 32 bits and for 93% of the cases with two errors in the FEC block. We will assume worst case and say for three or more errors in the FEC block, it will always corrupt the CAI. Therefore, the probability of correct CAI is as follows:

$$P(\text{correct CAI}) = P(0 \text{ errors in FEC block}) + P(1 \text{ error in FEC block}) + .93\, P(2 \text{ errors in FEC block})$$

$$\text{where } P(i \text{ errors in FEC block}) = \binom{32}{i} Pe^{i} (1-Pe)^{32-i}$$

$$P(\text{correct CAI}) = (1-Pe)^{32} + 32Pe(1-Pe)^{31} + (.93)(496)Pe^{2}(1-Pe)^{30}$$

The probability of corrupt CAI is as follows:

$$P(\text{corrupt CAI}) = 1-P(\text{correct CAI})$$

The mean time between corrupt CAI is as follows:

$$T(\text{CAI corrupt}) = \frac{6 \text{ millisec}}{P(\text{corrupt CAI})}$$

The probability of corrupt CAI and the mean time to corrupt CAI are evaluated and shown in Table 3-1.

3.2.1.5.4 Conclusions

In order to draw any conclusions from Table 3-1, we must consider not only the effects of the corrupted CAI, but also the effects of the BER on the speech channel. If a channel is operating at a BER of 10^{-3} there will be lots of pops and clicks already on the channel. If the CAI gets corrupted once every 2.5 minutes while the BER is 10^{-3} on the channel it may be difficult for the average listener to distinguish between the types of noise pops generated. From the 10^{-3} BER the listener will be getting about 32 bit errors per second. However, from the CAI corrupti n there will only be a short 6 ms burst of noise at a much lower frequency. Keeping this in mind it would seem that the CAI corruption is within acceptable limits. In most systems the BER is maintained above 10^{-4} which results in almost no noticeable degradation from CAI corruption.

3.2.1.6 Overload Protection

The DCEM has a maximum number of bits that can be transmitted each frame over the transmission facility. All of the data and speech channels are allocated bits from this number. Each data channel gets 8 bits; therefore, the more data channels, the fewer the bits left over for speech channels. The DCEM maintains a minimum of 3 bits per active speech sample.

Table 3-1. Probability of Corrupt CAI

Channel Error Rate	P(Corrupt CAI)	T(CAI Corrupt)
1×10^{-3}	3.85×10^{-5}	2.59 min
1×10^{-4}	3.51×10^{-7}	4.75 hours
1×10^{-5}	3.48×10^{-9}	20 days
1×10^{-6}	3.5×10^{-11}	5.4 years

If the loading is high enough such that less than 3 bits are available for each active speech channel, front end clipping is introduced on newly active channels and the channel is not allowed to be transmitted until 3 bits can be allocated. Additional protection is provided by setting a limit on the maximum number of data channels. The user can set the maximum number of digital and modem data channels allowed. If additional data channels are detected once the maximum programmed number is exceeded, the channel is treated as a speech channel and sent through the ADPCM algorithm.

In all cases, if there are no data channels, there is no clipping. As the number of data channels increases so do the chances of introducing clipping. Below, the probability of clipping is calculated as a function of the number of data channels. This analysis is for operation in mode A with an activity factor (α) of 0.38. Since there are 180 bits per frame for transmitting compressed speech and data and clipping is introduced for $L < 3$, clipping can occur when:

$$\frac{\text{180 compressed data bits - 8D}}{\text{3 bits per speech channel}} < \text{48 channel - D}$$

Where D = the number of data channels.

Solving the above inequality shows that clipping can occur if there are more than seven data channels. If it is assumed that all 48 possible channels are off-hook (seized) then we can calculate the probability of having clipping. For example, if there are 12 data channels then there are 48 - 12 = 36 possible speech users. Clipping will occur when more than 28 speech channels are active. With α = 0.38 the probability of more than 28 speech channels being active is

P (more than 28 active speech channels) =

$$\sum_{i=29}^{36} \binom{36}{i} (0.38)^{i} (0.62)^{36-i} = 2.22 \times 10^{-7}$$

Table 3-2 list the probabilities of clipping as a function of the number of data channels. It is clear from Table 3-2 that even with the maximum number of data channels (16), clipping is fairly insignificant. However, since the user has the option of limiting the number of data channels, he can eliminate clipping totally if he wishes.

3.2.2 Other Compression Features

In addition to the DSI/ADPCM, compression modes provide the following features:

- Choice of single frequency (SF) or E and M signaling
- Microprocessor orderwire
- Channel preassignment to data, off, speech, or normal
- Provide local end or remote end statistical data on the efficiency and operation of the DCEM.

3.2.2.1 SF Signaling

SF tones (2600 Hz while onhook) may be used with the DCEM. Normally these tones are detected as a modem data channel and

Table 3-2. Probability of Front End Clipping

Number of Data Channels	Maximum Number of Speech Channels	Number of Speech Channels Required to Introduce Clipping	Probability of Introducing Clipping
0	48	> 48	0
1	47	> 47	0
2	46	> 46	0
3	45	> 45	0
4	44	> 44	0
5	43	> 43	0
6	42	> 42	0
7	41	> 41	0
8	40	39	1.03×10^{-15}
9	39	37	8.33×10^{-14}
10	38	34	6.04×10^{-11}
11	37	31	1.40×10^{-8}
12	36	29	2.22×10^{-7}
13	35	26	1.41×10^{-5}
14	34	23	4.40×10^{-4}
15	33	21	2.51×10^{-3}
16	32	18	2.75×10^{-2}

Assume: 48 Offhook channels with = 0.38

transmitted as an 8-bit data channel. The DCEM detects the presence of this tone and forces the channel inactive. On the receive end, the DCEM reconstructs the SF tone, making it transparent to users.

3.2.2.2 Microprocessor Orderwire

The DCEM allows the transmission of an ASCII message between DCEM terminals, to allow link communications or remote control.

3.2.2.3 Channel Preassignment

The DCEM allows the operator the flexibility to bypass the detected signal type and preset it to a predetermined value. Four types are available:

- Data channels - Each data channel is assigned 8-bit PCM per sample.
- Inactive - No bits are allocated to a channel set to inactive.
- Speech - A speech channel cannot be detected as a modem channel.
- Normal - The DCEM determines the type of signal present and processes it appropriately.

3.2.2.4 Statistical Data

The following data is provided approximately every 66 minutes automatically or about one minute after entering the "SS" command:

- Average number of active speech channels. In Mode A, if all 48 channels are offhook and carrying speech, this number divided by 48 yields the activity factor.

- Average number of active data channels.

- Average distribution of L in percent. L is the number of bits per active speech channel and varies from 8 to 3. This item gives the average percent of time that each value of L is used.

- Total channel-multiframes that detected data is sent as speech due to the maximum number of data channels being exceeded. This number can be manually converted to channel-seconds by dividing it by 167 in mode A and B, by 250 in mode C, or by 125 in mode I.

- Total channel-half-multiframes that detected active channels are not sent in order to prevent L from falling below the minimum allowable value. This number can be manually converted to channel-seconds of freeze-out by dividing it by 333 in mode A and B, by 500 in mode C, or by 250 in mode I.

- A listing of the preset assignment of each channel, i.e., Data, Speech, Idle, or Normal.

3.3 RATE CONVERSION

In modes D and E, the rate conversion modes, two channel banks are allowed to communicate through higher bit rate transmission facilities. Since only bit stuffing is used, the input format of the data is not important. This allows transmission of specially formatted data; for example, encrypted or D1 channel bank data.

3.4 FORMAT CONVERSION

In modes F through H, D2/D3 and CEPT, channel banks are allowed to communicate. The features of these modes are as follows:

- Companding conversion in accordance with CCITT
- Signaling conversion between the two standards
- Unequipped channels are forced off.

3.5 DCEM IMPLEMENTATION

Below is a description of the DCEM system. It is divided into three major sections: frame formats, hardware description, and software description.

3.5.1 Frame Formats

Below is a description of the frame structures used on the DCEM. See Figure 3-14. The description is divided into a discussion of the channel bank, compression, rate conversion, and format conversion frame formats.

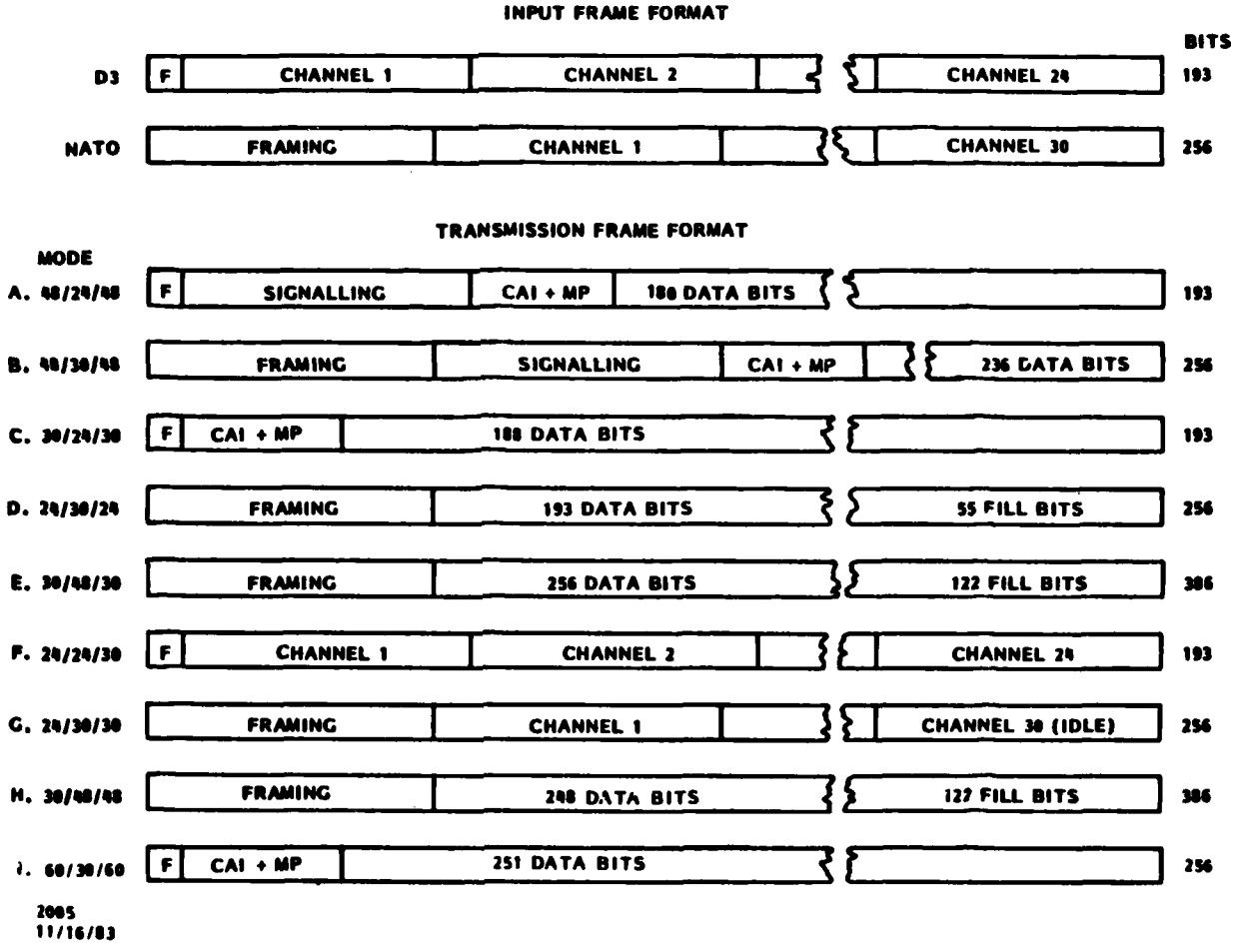


Figure 3-14. Frame Formats

3.5.1.1 Channel Bank Frame Formats

Channel bank outputs are input into the DCEM for processing. There are two standard channel bank inputs used by the DCEM. These are the North American Bell standard and the European CEPT standard. Each is described below.

3.5.1.1.1 Bell Standard

The Bell standard used in North America has two formats: the D2 and the D3 type channel banks. The DCEM is compatible with both. A description of this standard is given in Figure 3-15.

3.5.1.1.2 CEPT Standard

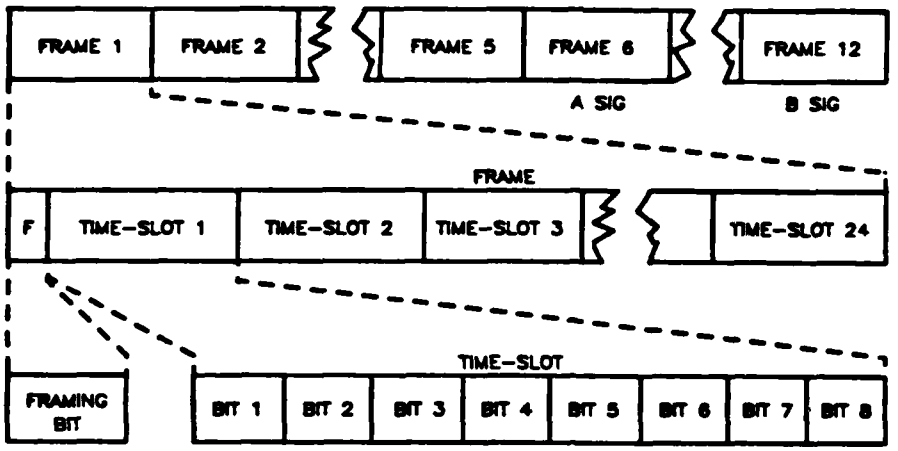
The CEPT standard used in European countries is described in Figure 3-16.

3.5.1.2 Compression Frame Formats

Below is a description of frame formats used in compression modes. Each frame is divided into the following fields:

- Framing Bits - the framing bit patterns are shown in Table 3-3.

- Signaling Bits - In modes A and B when a T1 format frame is being received, signaling bits are received in the LSB of the PCM samples on the 6th and 12th frames. These bits are extracted and grouped into 8-bit groups in the DSI frame, as shown in Table 3-4. In the CEPT format,



1. EACH MULTIFRAME (2316 BITS, 1.5 msec) CONSIST OF 12 FRAMES.

2. EACH FRAME (193 BITS, 125 microsec) CONSISTS OF 24 EIGHT BIT TIME-SLOTS PLUS A FRAMING BIT.

3. THE FRAMING BITS OF EACH MULTIFRAME FOLLOW THE FOLLOWING PATTERN: 100011011100 (THE ODD BITS ARE FRAMING BITS AND THE EVEN BITS ARE MULTIFRAMING BITS)

4. EACH TIME-SLOT CONSISTS OF 8 BITS. THE TIME-SLOTS OF FRAME 6 CONTAIN 7 BIT PCM WORDS PLUS THE A SIGNALING BIT IN BIT 8. THE TIME-SLOTS OF FRAME 12 CONTAIN 7 BIT PCM WORDS PLUS THE B SIGNALING BIT IN BIT 8. ALL OTHER FRAMES CONTAIN 8 BIT PCM WORDS.

5. THE VOICE CHANNELS ARE ARRANGED IN THE TIME SLOTS AS FOLLOWS:

TIME-SLOT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
D2 CHANNELS	12	13	1	17	5	21	9	15	3	19	7	23	11	14	2	18	6	22	10	16	4	20	8	24
D3 CHANNELS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

6. THE 24 VOICE CHANNELS ARE ENCODED USING 8 (OR 7) BIT FOLDED BINARY PCM WITH 15 SEGMENT μ255 COMPANDING.

7. THE OVERALL BIT RATE IS 1.544 Mb/sec.

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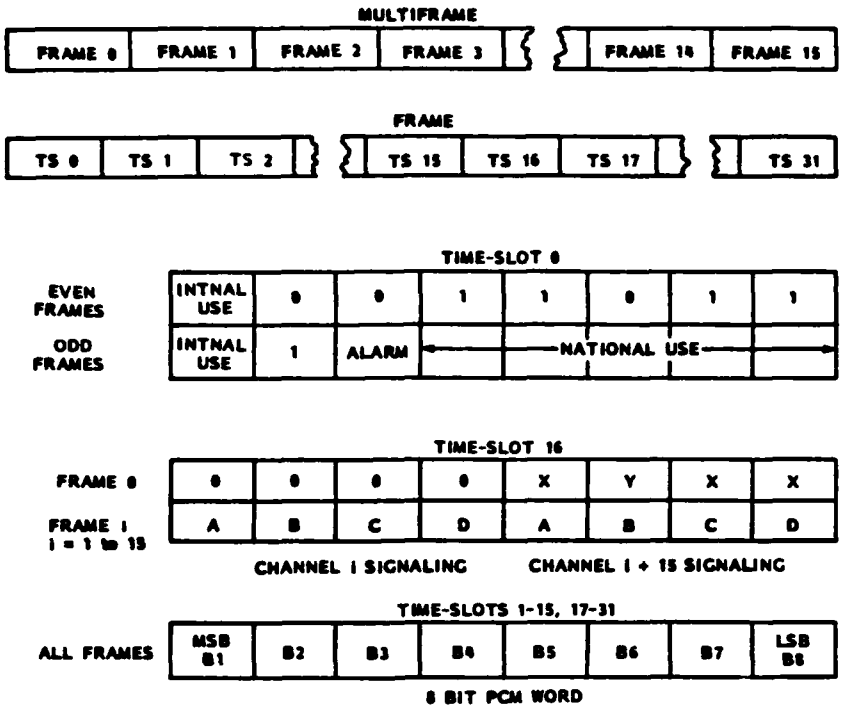
Figure 3-15. D2/D3 Frame Format



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1. EACH MULTIFRAME (4096 BITS, 2.0 msec) CONTAINS 16 FRAME NUMBERED FROM 0 TO 15.
2. EACH FRAME (256 BITS, 125 microsec) CONTAINS 32 EIGHT BIT TIME-SLOTS NUMBERED FROM 0 TO 31.
3. TIME-SLOT 0 OF EVEN FRAMES CONTAINS THE FRAMING BITS (X0011011).
4. TIME-SLOT 16 OF FRAME 0 CONTAINS THE MULTIFRAME ALIGNMENT SIGNAL (0000XYXX) WHERE THE X's ARE SPARE AND Y IS AN ALARM BIT. TIME SLOT 16 OF FRAMES 1-15 CONTAIN THE A, B, C, AND D SIGNALING PATHS OF THE 30 CHANNELS.
5. THE OTHER TIME-SLOTS CONTAIN 8 BIT PCM WORDS WITH BITS 2,4,6, AND 8 INVERTED, WITH A87.6 LAW COMPANDING.
6. THE OVERALL BIT RATE IS 2.048 Mb/sec.

Figure 3-16. CEPT Frame Format

Table 3-3. Framing Bit Patterns

MODE	MULTI-FRAME LENGTH	MULTIFRAME PATTERN	MULTIFRAME PATTERN LOCATION	FRAME PATTERN	FRAME PATTERN LOCATION
A*	48	111 111 111 111 111 111 001 110	First bit on even frames	101 010 101 010 101 010 101 010	First bit on odd frames
B*	48	111 111 111 111 111 111 001 110	First bit on even frames	101 010 101 010 101 010 101 010	Timeslot 0
C*	32	111 111 111 100 111 0	First bit on even frames	101 010 101 010 101 0	First bit on odd frames
D	1	None	N/A	101 010 101 010 101 0	Timeslot 0
E	1	None	N/A	10000001 X1XXXXXX	Timeslot 0
F*	12	001110	First bit on even frames	101010	First bit on odd frames
G	16	0000XXXX	Timeslot 16 on frame 0	X0011011 X1XXXXXX	Timeslot 0
H	16	0000XXXX	Timeslot 16 on frame 0	X0011011 11011111	Timeslot 0
I*	64				

*NOTE: In Modes A, B, C, F, and I the first frame in the multiframe is an odd frame (frame 1).

Table 3-4. Transmitted Signaling Bits in Modes A and B

Frame Address				PCM Terminal Number	Transmitted Signaling							
					1	2	1	2	1	2	1	2
0	12	24	36		A1	A1	A2	A2	A3	A3	A4	A4
1	13	25	37		A5	A5	A6	A6	A7	A7	A8	A8
2	14	26	38		A9	A9	A10	A11	A11	A12	A12	A12
3	15	27	39		A13	A13	A14	A14	A15	A15	A16	A16
4	16	28	40		A17	A17	A18	A18	A19	A19	A20	A20
5	17	29	41		A21	A21	A22	A22	A23	A23	A24	A24
6	18	30	42		B1	B1	B2	B2	B3	B3	B4	B4
7	19	31	43		B5	B5	B6	B6	B7	B7	B8	B8
8	20	32	44		B9	B9	B10	B10	B11	B11	B12	B12
9	21	33	45		B13	B13	B14	B14	B15	B15	B16	B16
10	22	34	46		B17	B17	B18	B18	B19	B19	B20	B20
11	23	35	47		B21	B21	B22	B22	B23	B23	B24	B24

signaling bits are already grouped into separate timeslots and are included in the DSI frame unmodified.

- Channel Assignment Bits - These bits provided information on the dynamic assignment of the remaining bits in the DSI frame. These bits are discussed in detail in Subsection 3.5.1.2.1.

- Data Channel Bits - Digital or voice band data channels are transmitted as unmodified 8-bit samples.

- Speech Channel Bits - The remaining bits in the frame are divided among the active voice channels. This determines the ADPCM word length.

- Fill Bits - When loading is light and all active speech channels are assigned 8 bits, there may be bits left over.

3.5.1.2.1 Channel Assignment Information

The DCEM in compression modes classifies each input channel into one of three categories: inactive, speech, or data. This classification determines how the output frame is put together. Inactive channels are not allocated any bits, speech channels are allocated L-bits, and data channels are allocated 8 bits. This compression of input channels has to be expanded on the receive side; therefore, information on how the bits in the frame are divided up is transmitted to the receive side. This information is called Channel Assignment Information (CAI).

CAI is sent to the receive side in its own frame format. This information is error correction encoded to reduce transmission errors

in this data. The CAI consists of four data types: activity bits, data bits, microprocessor channel bits, or parity bits. Each input channel has an activity bit and a data bit, as shown in Table 3-5, which determines the channel's classification.

Microprocessor channel bits are used for control and orderwire communications between the transmit and receive sections of the DCEM. The parity bits are used for error correction purposes.

3.5.1.2.1.1 Error Encoding of CAI

The CAI is error correction encoded using a modified Hamming code. It is a (32,26) block code. For each 26 data bits, there are 6 parity check bits. Five of these bits are generated from the (31,26) Hamming code with $G(x) = x^5 + x^2 + 1$. The other parity bit is an overall parity check bit. The code is capable of correcting single errors and detecting double errors. Detected double errors force the receive side to use the same CAI as previously used to minimize the probability of error.

3.5.1.2.1.2 CAI Frame Format

Each frame, 4 bits of CAI are transmitted, as shown in Tables 3-6, 3-7, and 3-8. Each eight frames, a 32-bit block is formed for the CAI error encoder. This block contains 24 bits of assignment information, 2 bits of microprocessor data and 6 parity bits. Tables 3-6, 3-7, and 3-8 indicate how many blocks it takes to complete a multiframe.

Table 3-5. CAI Classification

Activity Bit	Data Bit	Result
0	0	Inactive
0	1	Inactive
1	0	Speech Channel
1	1	Data Channel

Table 3-6. Channel Assignment Encoding for Modes A & B

Bit#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Block 1	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	M	M	P	P	P	P	P	P
Frame	2				3				4				5				6				7				8				9			
Block 2	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	D23	D24	M	M	P	P	P	P	P	P
Frame	10				11				12				13				14				15				16				17			
Block 3	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38	A39	A40	A41	A42	A43	A44	A45	A46	A47	A48	M	M	P	P	P	P	P	P
Frame	18				19				20				21				22				23				24				25			
Block 4	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	M	M	P	P	P	P	P	P
Frame	26				27				28				29				30				31				32				33			
Block 5	D25	D26	D27	D28	D29	D30	D31	D32	D33	D34	D35	D36	D37	D38	D39	D40	D41	D42	D43	D44	D45	D46	D47	D48	M	M	P	P	P	P	P	P
Frame	34				35				36				37				38				39				40				41			
Block 6	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38	A39	A40	A41	A42	A43	A44	A45	A46	A47	A48	M	M	P	P	P	P	P	P
Frame	42				43				44				45				46				47				0				1			

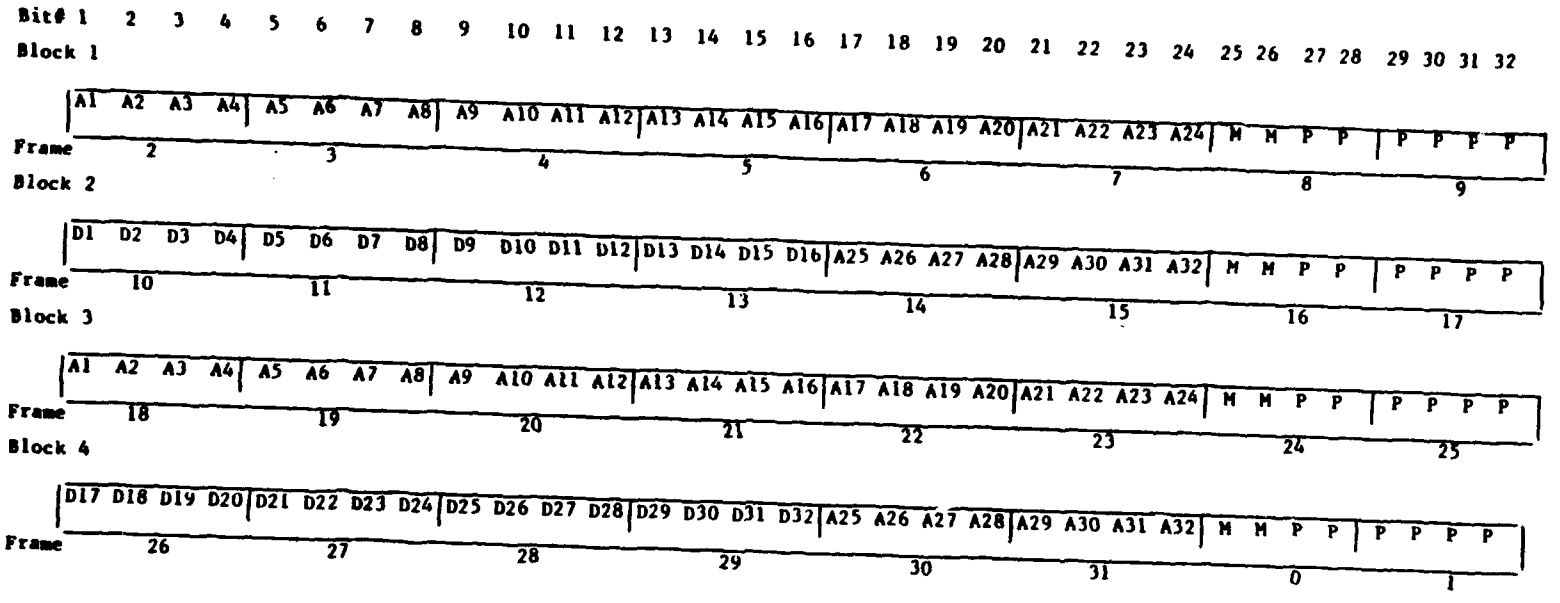
A = Activity bit followed by channel represented (1=ON/0=OFF)

D = Data bit followed by channel represented (1=DATA/0=SPEECH)

M = Bit provided by microprocessor

P = Parity check bit.

Table 3-7. Channel Assignment Encoding for Mode C



A = Activity bit followed by channel represented (1=ON/0=OFF)

D = Data bit followed by channel represented (1=DATA/0=SPEECH)

M = Bit provided by microprocessor

P = Parity check bit.

Table 3-8. Channel Assignment Encoding for Mode I

Bit#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Block 1																																
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	M	M	P	P	P	P	P	P
Frame	2				3				4				5				6				7				8				9			
Block 2																																
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	A25	A26	A27	A28	A29	A30	A31	A32	M	M	P	P	P	P	P	P
Frame	10				11				12				13				14				15				16				17			
Block 3																																
	A33	A34	A35	A36	A37	A38	A38	A40	A41	A42	A43	A44	A45	A46	A47	A48	A49	A50	A51	A52	A53	A54	A55	A56	M	M	P	P	P	P	P	P
Frame	18				19				20				21				22				23				24				25			
Block 4																																
	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31	D32	A57	A58	A59	A60	A61	A62	A63	A64	M	M	P	P	P	P	P	P
Frame	26				27				28				29				30				31				32				33			
Block 5																																
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	M	M	P	P	P	P	P	P
Frame	34				35				36				37				38				39				40				41			

A = Activity bit followed by channel represented (1=ON/0=OFF)

D = Data bit followed by channel represented (1=DATA/0=SPEECH)

M = Bit provided by microprocessor

P = Parity check bit.

NOTE: Continued on next page.

Table 3-8. Channel Assigrment Encoding for Mode I (Cont.)

Bit#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Block 6																																
	D33	D34	D35	D36	D37	D38	D39	D40	D41	D42	D43	D44	D45	D46	D47	D48	A25	A26	A27	A28	A29	A30	A31	A32	M	M	P	P	P	P	P	P
Frame	42				43				44				45				46				47				48				49			
Block 7																																
	A33	A34	A35	A36	A37	A38	A39	A40	A41	A42	A43	A44	A45	A46	A47	A48	A49	A50	A51	A52	A53	A54	A55	A56	M	M	P	P	P	P	P	P
Frame	50				51				52				53				54				55				56				57			
Block 8																																
	D49	D50	D51	D52	D53	D54	D55	D56	D57	D58	D59	D60	D61	D62	D63	D64	A57	A58	A59	A60	A61	A62	A63	A64	M	M	P	P	P	P	P	P
Frame	58				59				60				61				62				63				0				1			

A = Activ ~ bit followed by channel represented (1=ON/0=OFF)

D = Data bit followed by channel represented (1=DATA/0=SPEECH)

M = Bit provided by microprocessor

P = Parity check bit.

3.5.1.2.2 Speech Channel Bits

Each speech channel is assigned L-bit ADPCM words unless L = 8. For L = 8 PCM is transmitted for active speech channels. L is calculated based on the formula shown in Figure 3-17.

3.5.1.2.3 Idle Channels

Channels that are inactive are not allocated any bits. To prevent the listener from detecting a dead channel, some idle channel noise is added in on the receive side.

3.5.1.2.4 Scramblers

To maximize the ones density on the output of the DCEM transmitter, the output is scrambled. All CAI, microprocessor and data bits, as shown in Figure 3-14, are scrambled. The scrambler is a synchronous scrambler reset during the framing data. The generator polynomial is $g(x) = X^5 + X^2 + 1$.

3.5.1.3 Rate Conversion Frame Format

The rate conversion frame formats are shown in Figure 3-14. The frame consists of three parts: the framing bits, the data bits, and the fill bits. Framing bit patterns are shown in Table 3-3. The data bits are inserted into the frame pattern without respect to the input framing bit patterns. For this reason, encrypted data may be transmitted in this mode. The fill bit pattern is a repeated DF (Hex) pattern, normally. However, to provide for a DCEM CGA alarm, an all ones pattern is sent during this alarm for fill.

L_{MIN} = The Greatest Integer less than $\frac{N - 8D}{S}$

If L_{MIN} is less than 0 then L_{MIN} equals 0. If L_{MIN} is greater than 8, L_{MIN} equals 8.

$TC = N - 8D - S(L_{MIN})$

$$L = \begin{cases} L_{MIN} + 1 \text{ if less than or equal to TC speech channels have been processed in a frame} \\ L_{MIN} \text{ when the number of speech channels processed is greater than TC.} \end{cases}$$

If L is greater than 8, L equals 8.

where

A = The number of Active channels
D = The number of Data channels
S = The number of Speech channels
TC = Transition Count (where to change the value of L).

N	Mode
180	A
236	B
180	C
236	I

Figure 3-17. Calculation of L

3.5.1.4 Format Conversion Frame Formats

The format conversion frame formats in modes F and G are different than that of mode H; therefore, each is discussed separately.

3.5.1.4.1 Format Conversion in Modes F and G

Modes F and G are identical in their operation except for where the input and output connections are made. In these modes, there is only one DCEM used; therefore, the input is in one of the two standards discussed in Subsection 3.5.1.1 and the output is in the other standard. Each standard has its own format for framing, signaling and companding. The conversion between each of these different standards is handled in the DCEM.

3.5.1.4.1.1 Framing

Figures 3-15 and 3-16 show the differences between the input and output framing patterns.

3.5.1.4.1.2 Companding

The conversion between the Mu-Law to A-Law and A-Law to Mu-Law is done in accordance with Tables 3-9 and 3-10, taken from CCITT.

Since there are 30 channels in the CEPT standard and 24 channels in the Bell standard, there are six unequipped channels on the CEPT channel bank. The DCEM outputs a zero value for these channels (25-30).

Table 3-9. Mu-Law to A-Law Conversion

μ-law Decoder output value number	A-law Decoder output value number	μ-law Decoder output value number	A-law Decoder output value number
0	1	44	41
1	1	45	42
2	2	46	43
3	2	47	44
4	3	48	46
5	3	49	48
6	4	50	49
7	4	51	50
8	5	52	51
9	5	53	52
10	6	54	53
11	6	55	54
12	7	56	55
13	7	57	56
14	8	58	57
15	8	59	58
16	9	60	59
17	10	61	60
18	11	62	61
19	12	63	62
20	13	64	64
21	14	65	65
22	15	66	66
23	16	67	67
24	17	68	68
25	18	69	69
26	19	70	70
27	20	71	71
28	21	72	72
29	22	73	73
30	23	74	74
31	24	75	75
32	25	76	76
33	27	77	77
34	29	78	78
35	31	79	79
36	33	80	80
37	34	81	82
38	35	82	83
39	36	83	84
40	37	84	85
41	38	85	86
42	39	86	87
43	40	87	88
		.	.
		.	.
		.	.
		127	128

Table 3-10. A-Law to Mu-Law Conversion

A-law Decoder output value number	*μ-law* Decoder output value number	*A-law* Decoder output value number	*μ-law* Decoder output value number
1	1	51	52
2	3	52	53
3	5	53	54
4	7	54	55
5	9	55	56
6	11	56	57
7	13	57	58
8	15	58	59
9	16	59	60
10	17	60	61
11	18	61	62
12	19	62	63
13	20	63	64
14	21	64	64
15	22	65	65
16	23	66	66
17	24	67	67
18	25	68	68
19	26	69	69
20	27	70	70
21	28	71	71
22	29	72	72
23	30	73	73
24	31	74	74
25	32	75	75
26	32	76	76
27	33	77	77
28	33	78	78
29	34	79	79
30	34	80	80
31	35	81	80
32	35	82	81
33	36	83	82
34	37	84	83
35	38	85	84
36	39	86	85
37	40	87	86
38	41	88	87
39	42	89	88
40	43	90	89
41	44	91	90
42	45	92	91
43	46	93	92
44	47	94	93
45	48	95	94
46	48	96	95
47	49	97	96
48	49	98	97
49	50	.	.
50	51	.	.
		.	.
		128	127

3.5.1.4.1.3 Signaling

In these modes, C and D signaling bits used in the CEPT standard are not used in the Bell standard. Therefore, C and D signaling bits are not transmitted. C and D signaling input to the CEPT channel banks are C = 0, D = 1.

In addition, the two standards use different size multiframes: 12 and 16 frames, respectively. Therefore, in CEPT to Bell conversion, the signaling bits from every third CEPT multiframe will be repeated in two consecutive Bell multiframes. Signaling bits from each of the remaining CEPT frames will be placed in a single Bell multiframe. See Figure 3-18. In the Bell to CEPT direction, the signaling bits from every fourth Bell multiframe will be deleted. See Figure 3-19. Unequipped channels use A = 1, B = 1, C = 0, and D = 1.

3.5.1.4.2 Format Conversion in Mode H

Other than the addition of the frame format between the two DCEMs, this mode is similar to that of modes F and G. The difference is that 30 channels are equipped between the two Bell standard channel banks (time slots 1-15 each channel bank). The framing data between the DCEMs is shown in Figure 3-14 and Table 3-3. Fill pattern data is a repeated DF (Hex) pattern.

3.5.2 Hardware Description

The hardware functions are divided into two parts: the transmitter and the receiver. Each of these are discussed below and shown in the functional block diagram shown in Figure 3-20.

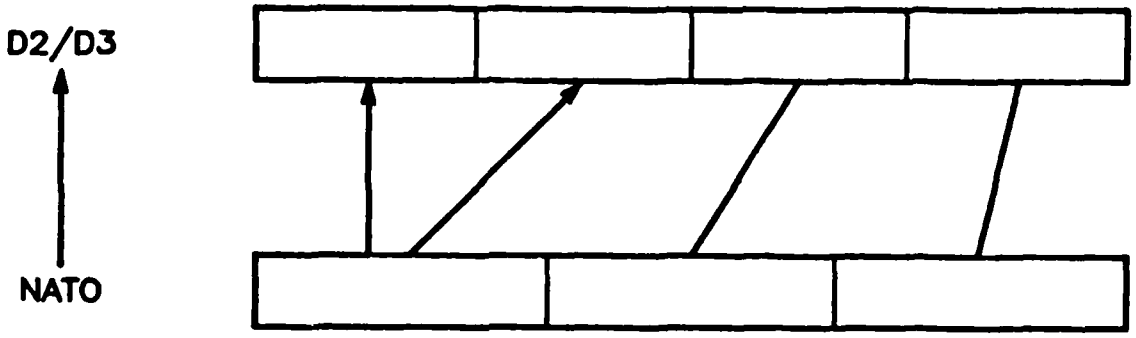


Figure 3-18. Signaling Conversion: CEPT to Bell

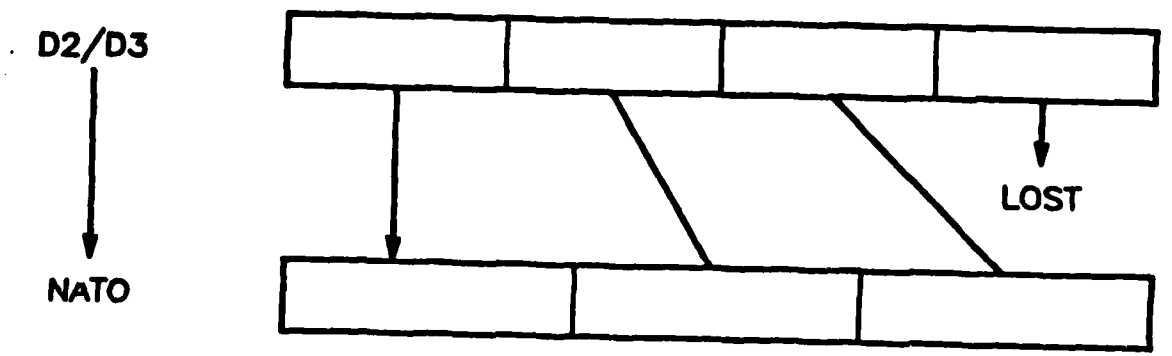


Figure 3-19. Signaling Conversion: Bell to CEPT

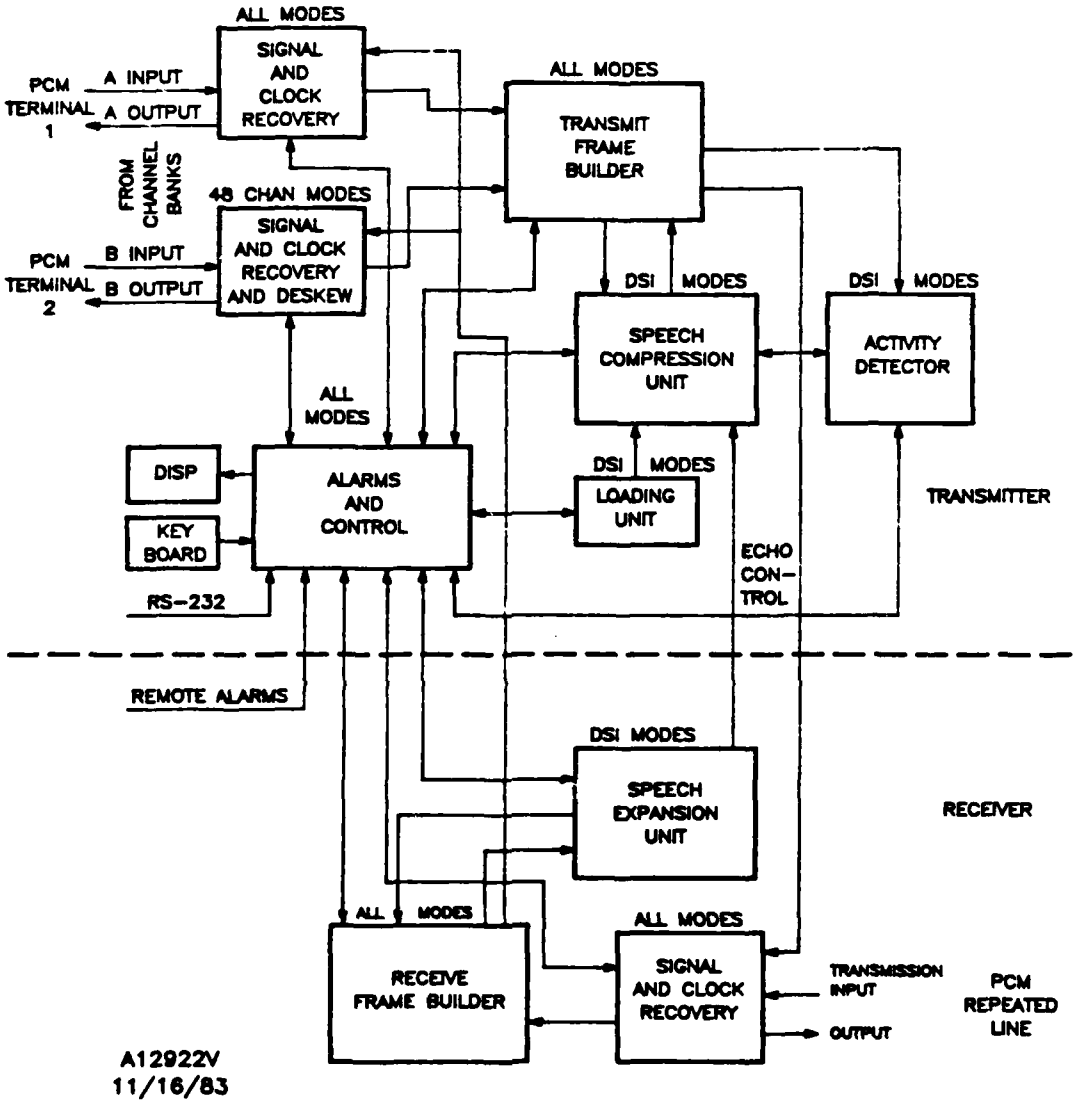


Figure 3-20. DCEM Block Diagram

3.5.2.1 Transmitter Functional Description

The DCEM Transmitter consists of the following functional blocks as shown in Figure 3-20 and described in the following subsections:

- Signal and Clock Recovery Unit
- Frame Builder
- Activity Detector
- Speech Compression Unit
- Alarm and Control Unit
- Loading Unit.

3.5.2.1.1 Signal and Clock Recovery Unit

The Signal and Clock Recovery Unit performs the functions listed below.

- Interfaces with all the transmission standards listed in Subsection 2.9.
- Extracts the bit timing clock from the incoming signal.
- Extracts the data from the incoming signal and decodes any line encoding.
- Searches for and locks to the framing patterns listed in Table 3-3. Frame and multiframe boundaries are identified.

- Generates the transmission signal with its associated line code described in Subsection 2.9 from the internal logic levels based on the selected mode of operation.

- Provides for a loopback mode which connects the local DCEM transmitter to the local DCEM receiver. An all ones patterns is transmitted to the far end DCEM unit during this mode of operation.

- Generates a loss of output alarm signal whenever the output data or timing is not transmitted for nominally 100 millisec or more.

- During operation in modes A, B, H, and I, the Signal and Clock Recovery Unit at input port PCM Terminal 2 will store the incoming data in a deskew buffer until the output of the deskew buffer is multiframe aligned with the data recovered from PCM Terminal 1, as shown in Figure 3-21.

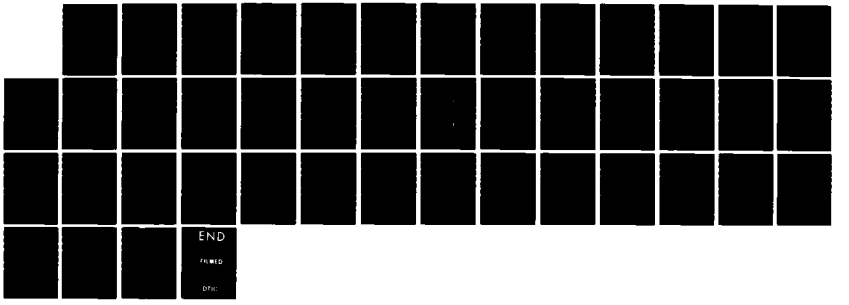
- Provides a loss of input signal alarm to the Alarm and Control Unit whenever the unit fails to receive data or timing (no transitions for nominally 100 ms or more). Whenever data and timing are present, the alarm will be deactivated.

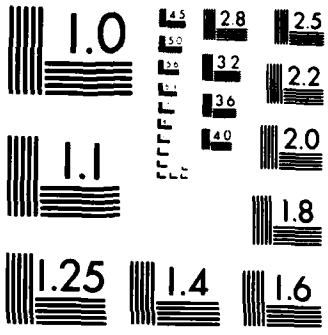
- Provides a loss of frame alarm to the Alarm and Control Unit whenever four consecutive frames have bit errors in their framing bit locations.

- Provides a loopback detect alarm to the Alarm and Control Unit.

AD-A150 084 DIGITAL CHANNEL EFFICIENCY MODEL(U) M/A-COM DCC INC GERMANTOWN MD D R LOWE SEP 84 RADC-TR-84-178 F30602-81-C-0025 2/2

UNCLASSIFIED F/G 17/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

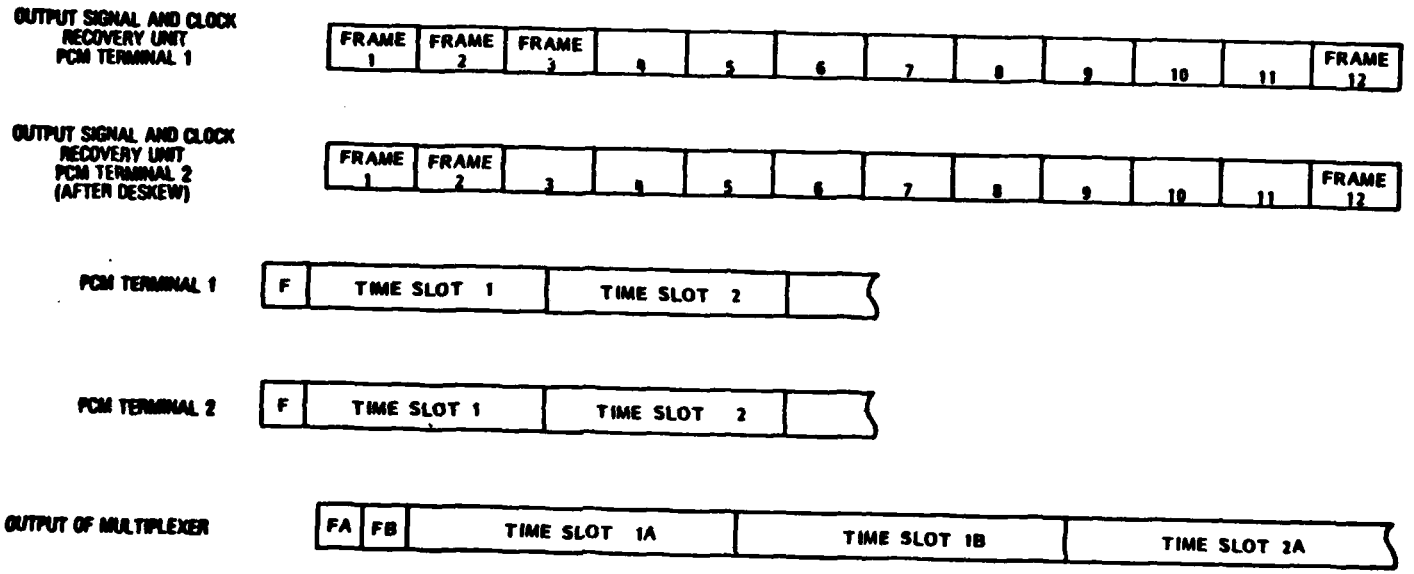


FIGURE 3-6. MULTIPLEXER OUTPUT IN MODES A AND MODES B ,

1542A
1/6/83

Figure 3-21. Multiplexer Output in Modes A and B

- Provides a signal which is active during each framing bit error to the Alarm and Control Unit.

The DCEM transmitter requires two of these units during operation in modes A, B, H, and I, and one unit otherwise. The DCEM receiver also uses one Signal and Clock Recovery Unit.

3.5.2.1.2 Transmit Frame Builder

The Transmit Frame Builder performs the following functions:

- Multiplexes the inputs from the two Signal and Clock Recovery Units, used during operation in modes A, B, H, and I into the word interleaved pattern shown in Figure 3-21.

- Converts Mu-Law encoded PCM samples to A-Law encoded samples and converts A-Law samples to Mu-Law samples, as defined in Tables 3-9 and 3-10, as required while operating in format conversion Modes F, G, and H.

- Passes PCM samples unaltered to the output frame during operation in modes D and E.

- Generates framing bits for the output frame as shown in Table 3-3.

- Constructs the transmission frame formats shown in Figure 3-14.

- Inserts fill bits into the transmission frame format for modes D, E, and H.

- Alters the output frame format in modes F, G, and H to send channel bank alarms and the DCEM CGA Alarm.

- Controls the data flow to and from the Speech Compression Unit.

- Buffers output frames to ensure that there is a continuous output.

- Generates all control signals not generated elsewhere.

- Extracts signaling bits, as described below, and inserts them into the transmission frame formats.

  - Modes A and B - The signaling bits are extracted from the LSB position of the PCM samples on frames 6 and 12, and grouped into twelve 8-bit groups as shown in Table 3-4. These bits are then inserted into the transmission frame as shown in Figure 3-14.

  - Modes C and I - The signaling bits are already grouped into 8-bit groups in time slot 16. The Speech Compression Unit will be forced to accept this input as a digital data channel, which automatically inserts this data into the transmission frame.

  - Modes D and E - No signaling extraction is required.

  - Modes G and H - A and B signaling bits are removed from the 6th and 12th frames of the Bell standard input, as described in Figure 3-15 and inserted into the CEPT

frame in time slot 16 as described in Figure 3-16. For bits not provided by the input, the following values are used: A = 1, B = 1, C = 0, D = 1.

- Mode F - CEPT standard A through D signaling bits are extracted from time slot 16 of the input, as described in Figure 3-16. The C and D bits are discarded and the A and B signaling bits for the 24 equipped channels are inserted into the LSB of the 6th and 12th frames of the Bell standard output, as described in Figure 3-15. Unequipped channels' signaling bits will be discarded.

3.5.2.1.3 Activity Detector

The Activity Detector performs the following functions:

- Determines if a channel is inactive or active and informs the Speech Compression Unit of this status
- Determines if an active channel has speech or voice band modem signals present and informs the Speech Compression Unit
- Detects the presence of SF tones, forces that channel inactive, and notifies the Alarm and Control Unit of its presence.

This unit is not required in modes D, E, F, G, and H.

3.5.2.1.4 Speech Compression Unit

The Speech Compression Unit performs the following functions:

- Delays input samples 4 millisec to prevent front end clipping.
- Generates the Channel Assignment Information (CAI) from the Activity Detector outputs and determines the number of bits allowed for each active speech channel.
- Converts PCM samples on active speech channels to L-bit ADPCM samples (where L = the number of bits assigned to each speech channel) using an ADPCM encoder.
- Bypasses data channels unaltered.
- Combines an external microprocessor data channel with the CAI, and error correction encodes this data.
- Multiplexes and buffers the ADPCM, PCM, and CAI data for the Transmit Frame Builder.

3.5.2.1.5 Alarm and Control Unit

3.5.2.1.5.1 Alarms Generated

Below is a list of alarms generated in the DCEM system:

- Input power supply - A white lamp, located on the power supply module, indicates that the primary alternating

current (ac), or direct current (dc) power has been applied to the DCEM modules. Whenever power is lost or the protective circuit breaker operates, the lamp will be extinguished.

- Module power - A green lamp is lit whenever primary power is provided to the DCEM system and all the dc outputs of the power supply are functioning. The lamp will be extinguished when any dc output of the power supply fails.

- Loss of frame alarm - When a Signal and Clock Recovery Unit detects a loss of frame alarm, the Alarm and Control Unit will monitor the event.

- Loss of output alarm - When a Signal and Clock Recovery Unit detects a loss of output alarm, the Alarm and Control Unit will monitor the event.

- Loss of input alarm - When a Signal and Clock Recovery Units detects a loss of input alarm, the Alarm and Control unit will monitor the event.

- Loopback alarm - During operation in the loopback mode and when the Receive Signal and Clock Recovery Unit detects a loopback alarm, the Alarm and Control Units on both ends of the channel will light a yellow lamp indicating this event.

- Carrier group alarm - When the loss of frame alarm has been present for 300 millisec $\pm$100 millisec, or if any of the other alarms listed above are present on the transmitter, the carrier group alarm will be transmitted

by the Transmit Frame Builder to the Receive Frame Builder. The Receive Frame Builder will notify the Alarm and Control Unit which will light a yellow lamp indicating this condition.

- Fault alarm - When a built-in test fails in the DCEM, a red lamp will be lit to indicate this condition.

For each of the alarms listed above, a contact closure, with separate contacts isolated from ground and capable of carrying 1 ampere continuously with normally open and normally closed outputs, will be provided at a connector.

3.5.2.1.5.2 Control Functions

Below is a list of control functions performed by the Alarm and Control Unit. A keypad device and alphanumeric display is provided to assist in operator control. An RS-232C port is provided for optional CRT control also. See reference 5 for details on operator commands.

- Allows for presentation of the status of any input channel.
- Allows for the selection of the mode configuration.
- Transmits status and control information to the Receiver.
- Provides user feedback on its operation.
- Provides a watchdog timer to prevent getting into a software infinite loop.

3.5.2.1.6 Loading Unit

The Loading Unit performs the function of fully loading the DCEM as described in Subsection 5.1.2, so that the performance test described in Subsection 5.1.4 can be made.

3.5.2.2 RECEIVER FUNCTIONAL DESCRIPTION

The DCEM Receiver consists of the following functional blocks as shown in Figure 3-20:

- Signal and Clock Recovery Unit
- Receive Frame Builder
- Speech Expansion Unit.

3.5.2.2.1 Signal and Clock Recovery Unit

This module is identical to the DCEM Transmitter Signal and Clock Recovery Unit. See Subsection 3.5.2.1.1 for details.

3.5.2.2.2 Receive Frame Builder

This mode is identical to the DCEM Transmit Frame Builder (see Subsection 3.5.2.1.2). In addition to the previously listed functions, it also performs the following receiver functions:

- Controls the data flow to and from the Speech Expansion Unit.

- Buffers the input frames to allow for different transmission and receive bit rates.

- Converts A-Law encoded PCM samples to Mu-Law encoded samples and converts Mu-Law samples to A-Law samples as defined by Tables 3-9 and 3-10, as required while operating in format conversion modes F, G, and H.

- Removes fill bits in modes D, E, and H.

- Removes signaling bits from the received frame formats shown in Figure 3-14 and inserts them into the output frame format as follows:

  - Modes A and B - During the 6th and 12th frames the 96 received signaling bits, as shown in Table 3-4, are inserted into the LSB position of each time slot.

  - Modes C and I - The Speech Expansion Unit assigns time slot 16 as a data channel which will ensure that the signaling bits are inserted into the output frame correctly.

  - Modes D and E - No signaling insertion is required.

  - Modes G and H - A through D signaling bits are extracted from time slot 16 of the input as described in Figure 3-16. The unused signaling bits from C and D and unequipped channels are discarded. For the 24 equipped channels A and B signaling bits are inserted

into the 6th and 12th frames of the output as described in Figure 3-15.

- Mode F - A and B signaling bits are removed from the LSB of the 6th and 12th frames of the input, as described in Figure 3-15, and inserted into the output frame in time slot 16, as described in Figure 3-16. For bits not provided by the input, the following values are used: A = 1, B = 1, C = 0, and D = 1.

- Generates and inserts framing bit sequences, as shown in Table 3-3.

3.5.2.2.3 Speech Expansion Unit

The Speech Expansion Unit performs the following functions:

- Removes the error correction code from the CAI and microprocessor data. If an error is detected and not corrected, the previous CAI will be used.

- Removes microprocessor data from the CAI and provides it to the Alarm and Control Unit.

- Determines which channels are data and which are speech, and allocates the proper number of bits to each channel based on the received CAI.

- Converts from ADPCM to PCM on active speech channels.

- Inserts idle channel noise into the inactive channels.

- Multiplexes the data channels, ADPCM decoded data, and idle channel noise and provides it to the Receive Frame Builder.

- Provides a signal to the Activity Detector indicating active receive channels to allow for echo control.

- Generate SF tones on channels selected by the Alarm and Control Unit.

3.6 SOFTWARE REQUIREMENTS

The control of the DCEM is handled through the user interface to the microprocessor based Alarm and Control Unit. This interface is made possible by commands which are under software control. The software requirements of the DCEM are as follows:

- Mode selection
- Channel preselection
- Status indication
- Alarm processing
- Nonvolatile storage of operational parameters
- Communication between DCEMs.

3.6.1 User Interface to the DCEM

There are three methods by which the operator controls the DCEM: the keypad and display, CRT, and external connectors.

3.6.1.1 Keypad and Display

The keypad is a 16-key keypad with alphanumeric keys. Each key contains three symbols, all in a different color. This keypad has a total of 46 symbols for use. The two control keys, located in the lower right, control which of the three symbols is selected on the other keys.

The display is a 16-character alphanumeric display with 8 characters on two rows. The combination of the keypad and display is capable of controlling all functions of the DCEM.

3.6.1.2 CRT

An RS-232C interface, as described in Subsection 2.10.1, Table 2.1, has also been provided for an optional CRT or remote control capability. Once the CRT is used for command entry, all outputs are to the CRT and not the display. To use the display once again, the keypad must be used for command entry.

3.6.1.3 Connector Control

There are two connectors, the loopback and frame search inhibit connectors, which can be used to set up their respective operations. These functions are activated by applying a ground level at their input connector.

3.6.2 Mode Selection

There are nine different modes of operation, some of which have two possible interface standards at each of three possible I/O

ports. The selection of these modes is controlled by command inputs. In response to the commands, each PC module is provided special parameter inputs, which forces the DCEM into the desired mode of operation.

3.6.3 Channel Preselection

In some cases, certain channel inputs will have known characteristics which may require overriding the normal processing performed by the DCEM. In these cases, the DCEM allows channel preselection values to be set by the operator. In compression modes (A, B, C and I), the channels can be set to:

Inactive - No bits allocated
Data - Always 8 bits allocated
Speech - Cannot be detected as a modem channel
Normal - Uses the value determined by the DCEM.

3.6.4 Status Indication

In addition to the statistical data, discussed in Subsection 3.2.2.4, alarm data, parameter settings, and channel preset values are displayed periodically or can be requested at any time through command entry.

3.6.5 Alarm Processing

The software is responsible for interrogating the PC modules in the DCEM for alarm conditions and taking proper action. This might be lighting an LED, closing a relay, printing an alarm message, or programming one of the modules to produce some special error pattern in its data output.

3.6.6 Nonvolatile Storage

All mode information and channel preselection values are stored in nonvolatile storage to ensure that the DCEM will return to the same mode of operation after a power failure.

3.6.7 Communication Between DCEMs

Communications between the DCEMs in compression modes is needed to send control status and alarm information. This is accomplished through the microprocessor channel between the units. This information is sent in packets as shown in Figure 3-22.

If the message is received correctly, an acknowledge message is sent back to the sending DCEM. If the message is received incorrectly or acknowledge is not received correctly at the sending DCEM, the message is retransmitted up to four times. If after four tries the message is not received correctly, an error message is displayed indicating there must be a problem with the transmission channel.

IDLE	BOM	SF DATA	MESSAGE DATA	EOM	CHECKSUM	IDLE

where:

IDLE is at least 2 bytes of FF Hex

BOM is the unique word 82 Hex

MESSAGE DATA is always in 8-bit ASCII code that represents the message being sent

SF DATA is 8 bytes of data representing the presence of an SF tone

EOM is the unique word 84 Hex

CHECKSUM is a parity check on the message.

Figure 3-22. Microprocessor Channel

SECTION 4.0
SUMMARY OF TESTING PROGRAM

4.1 INTRODUCTION

In addition to the extensive testing at all levels which are normal to a development program, there were three official phases of the DCEM test program: the plant acceptance test, the field acceptance test, and the operational test and evaluation. A brief summary of these test phases are presented below. Reference 6 presents a detailed test report on the test performed.

4.2 PLANT ACCEPTANCE TEST

The plant test was performed at M/A-COM DCC facilities between August, 22, 1983 and August 25, 1983. The purpose of this test was to demonstrate the DCEM's compliance to the Prime Item Development Specification (see reference 1). There were four phases of testing performed during this program: Electrical, Mechanical, Electromagnetic compatibility, and Functional performance.

4.2.1 Electrical Test

Electrical tests were used to demonstrate compatibility with the I/O interfaces. Timing tests and pulse mask tests were performed. In addition lockup protection and power supply compatibility were verified. M/A-COM DCC does not have the capability of fully testing the power supply, therefore, these test were performed at the facilities of National Power Technology. The test results are fully documented in the test report (see reference 6).

During the interface compatibility verification it was found that the pulse mask on the bipolar output exceeded the specification and that the rise time on the 3.088 Mbps NRZ clock was 2 nanosec too long. A design change was implemented during the testing program which brought the bipolar output signal within the desired pulse mask.

4.2.2 Mechanical Inspection Tests

The mechanical inspection tests were performed as part of the acceptance program. These tests required thorough mechanical and visual inspections to ensure that the quality of all materials and workmanship were in compliance with the Prime Item Development Specification.

4.2.3 Electromagnetic Compatibility Test

Electromagnetic Compatibility (EMC) Tests were performed on the DCEM per the Prime Item Development Specification. The DCEM was tested to selective MIL-STD-462 test requirements. These tests consisted of Powerline Conducted Emissions Test Method CE03 (20 kHz to 50 MHz), Radiated Electric Field Emissions Test Method RE02 (14 kHz to 35 MHz), and Spike Susceptibility Test Method CS06. These tests were performed at Spectrum Control Inc. between March 1, 1984 and March 6, 1984. The test results are given in reference 10.

4.2.4 Functional Performance Test

The Functional Performance test confirmed the DCEM's compliance to the function requirement stated in the Prime Item Development Specification. Below is a list of tests performed:

Mode Test

Voice Frequency Characteristics test consisting of

- Fully loaded requirements
- Insertion loss
- Idle channel noise
- S/N_q for 1004 Hz tone
- Envelope Delay Distortion
- Impulse Noise
- S/N_q for Speech

Frame Synchronization and Acquisition time

Monitor, Alarm, and Controls Functions

Single Frequency Test

Deactivation of 1 Channel Bank

Voice Band Data Detection.

4.3 FIELD ACCEPTANCE TEST

The field acceptance was conducted at the Scott Air Force Base facilities. The purpose of these tests was to ensure the DCEM properly interfaced to and worked with the military multiplexers. The DCEM was tested with the following military multiplexers: AN/FCC-98, AN/FCC-99 and CY104. These tests consisted of recording voice conversation at various loading conditions and Bit Error Rates (BER), testing modem compatibility, and the voice frequency measurements listed below:

Test Tone Level

Idle Channel Noise

Frequency Response

Envelope Delay

Loss Variation
Frequency Change
Single Tone Interference
Nonlinear Distortion
Impulse Noise
Phase Hit
Gain Hit
Drop Out
Termination Impedance
Phase Jitter
Amplitude Jitter
Signal-to-Noise Ratio

The above tests were conducted using automated test equipment provided by Scott Air Force Base. All tests passed except the Idle Channel noise test and Impulse noise test. The Idle Channel noise levels generated by the DCEM on inactive channel exceeded the specification requirement. Since this test the level has been decreased to within acceptable limits. The Impulse noise problem is caused by an increase in quantizing noise introduced by the ADPCM algorithm. As loading is increased the noise floor is also increased. This causes the impulse counter to increment as this quantizing noise level exceeds the preset Impulse noise level threshold. Therefore, the failure of the Impulse noise test is actually an indication of the increase in the expected quantizing noise and not the presence of Impulse noise.

4.4 OPERATIONAL TEST AND EVALUATION

The operational test was conducted over the 44JN03 1.544 Mbps link between Bann and Ramstein, West Germany, as shown in Figure 4-1. The purpose of the test was to demonstrate the DCEM

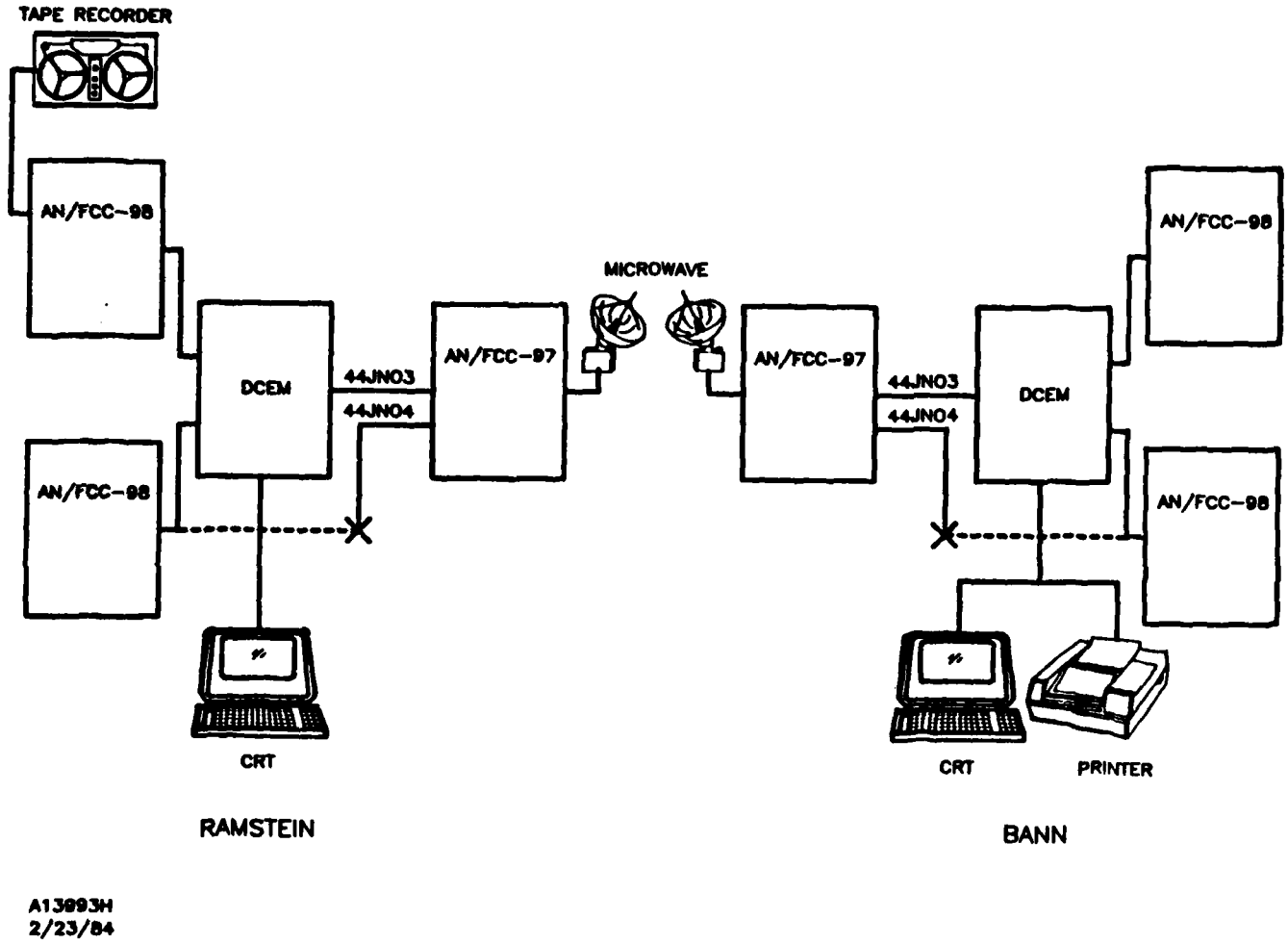


Figure 4-1. Operational Test Setup

capability of operating in a normal operation environment. In addition to passing normal operational traffic, the test also included determining the traffic loading cycle present on the link and making voice recordings during peak loading for analysis.

4.4.1 Gathering Statistics

In order to determine the traffic loading cycle, the following test data was taken each day the DCEM was operational. A printout of the data occurred approximately every hour.

1) Average number of active speech channels during the last hour. In this mode, if all 48 channels are offhook and carrying speech, this number divided by 48 yields the activity factor.

2) Average number of active data channels during the last hour.

3) Average distribution of L in percent. L is the number of bits per active speech channel and varies from 8 to 3. This item give the average percent of time that each value of L is used.

4) Total number of channel-multiframes of detected data that are sent as speech. This is due to the maximum number of data channels being exceeded. This number can be manually converted to channel-seconds by dividing it by 167 in Mode A.

5) Total number of channel-half-multiframes of detected active channels that are not transmitted to prevent L from falling below the minimum allowable value of 3. This number can be manually converted to channel-seconds of freezeout by dividing it by 333 in Mode A.

6) A listing of the preset assignment of each channel: i.e., Data, Speech, Idle, or Normal.

This statistical data was obtained over a period of six days from Thursday, September 9, 1983 to Tuesday, October 4, 1983. The data was analyzed for each day to yield the average number of bits per word throughout the day. Also, to show the effects of compression, a 0.3 activity factory was used to give an estimate of the average number of channels seized (offhook) throughout the day. This was determined by adding the total number of data channels to the speech channels divided by the activity factor.

4.4.2 Recordings

Recordings were made of voice conversations of at least one minute's duration on two different days.

Four voice recordings were made on Friday, September 30, 1983 at approximately 10:00 am, with the speech statistics shown in Table 4-1.

Three more voice recordings were made on Monday, October 3, 1983 at approximately 4 pm, with the statistics shown in Table 4-2.

Table 4-1. Speech Statistics September 30, 1983

Recording Number	Average # Speech chan.	Average Data chan.	Approximate bits/word (L)	Approximate chan. processed
1	3.93	15.58	7.81	28.68
2	3.27	15.40	7.91	26.30
3	6.30	15.84	7.33	36.84
4	4.91	15.61	7.77	31.98

Table 4-2. Speech Statistics October 3, 1983

Recording Number	Average # Speech chan.	Average Data chan.	Approximate bits/word (L)	Approximate chan. processed
1	9.66	16.19	5.34	48.00
2	8.29	16.28	6.04	43.91
3	7.17	16.20	6.88	40.10

4.4.3 Traffic Loading Cycle

Loading conditions of the 1.544 Mbps lines change during the day. The data provided by the DCEM was analyzed to show this traffic loading cycle. As can be seen in all of the statistics, there are a relatively large number of data channels present at all times. This is due to speech encryption equipment present on the phone lines. Figures 4-2 through 4-7 show graphs from the daily analysis of the traffic statistics. The information contained in each figure is derived from the tables accompanying each figure, Tables 4-3 through 4-8.

There was never an occurrence of freezeout during the testing period. The instances where data channels were sent as speech are shown on the daily analysis tables. This was due to the high loading of data channels on the system. However, no noticeable degradation was caused by the ADPCM algorithm on these data channels. Even though the system was heavily loaded with data channels, the distribution of bits remained in the L = 5-8 range with a corresponding decrease of only about 1-2 dB from the S/N_q of PCM. The periodicity of the statistics dumps being greater than one hour tends to give an averaging effect on the performance printout. As an example, when the recordings were made on Monday, average activity was about 42-45 channels with L = 5-7 bits per word, but the graph reflects an activity of about 36 channels with L approximately 7 bits. With this fact in mind, it can be seen that the compression is actually greater than that shown in the graph at times of heavy loading.

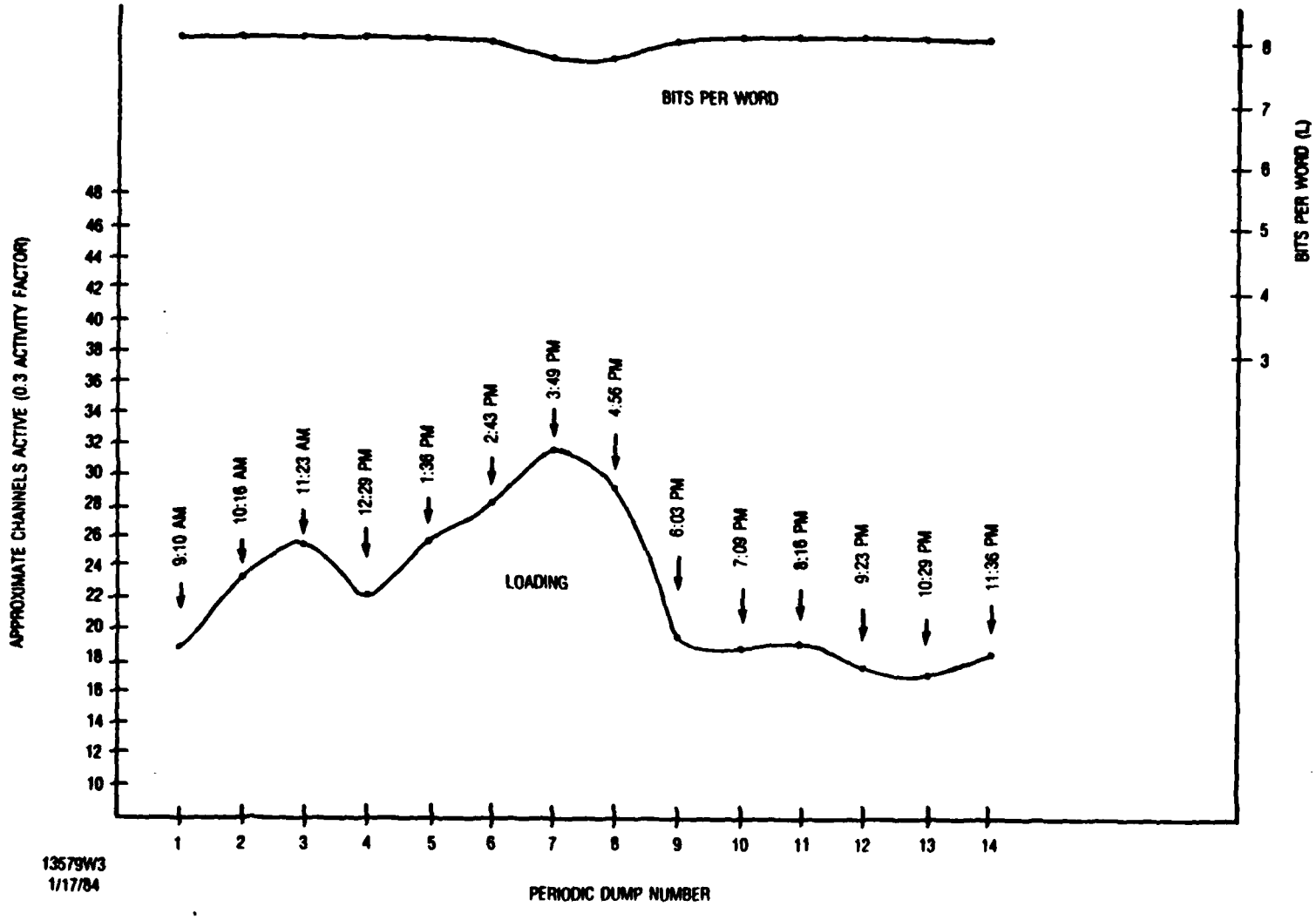


Figure 4-2. Traffic Analysis - Thursday September 9, 1983

Table 4-3. Speech Statistics - Thursday September 29, 1983

Time	Ave. Spch	Ave. Data	Ave. L	Ave. Data Sent as Speech	Ave. Channels Offhook Before DSI at .3 Activity Factor
9:10 am	1.53	13.64	8.0	1.01	18.74
10:16 am	2.77	14.42	7.99	0.12	23.65
11:23 am	3.19	15.30	7.99	0.41	25.93
12:29 am	2.10	14.98	8.0	0.19	21.98
1:36 pm	3.17	15.41	7.97	0.70	25.98
2:43 pm	3.81	15.39	7.95	0.71	28.09
3:49 pm	4.84	15.70	7.81	1.25	31.83
4:56 pm	4.01	15.60	7.84	1.04	28.97
6:03 pm	1.46	14.77	8.0	0.16	19.64
7:09 pm	1.22	15.03	8.0	0.21	19.10
8:16 pm	1.52	14.54	8.0	0.02	19.61
9:23 pm	0.90	14.31	8.0	0.02	17.31
10:29 pm	1.18	13.74	8.0	0.01	17.67
11:36 pm	1.28	14.41	8.0	0.02	18.68

Daily averages Spch = 2.36 channels
Data = 14.80 channels

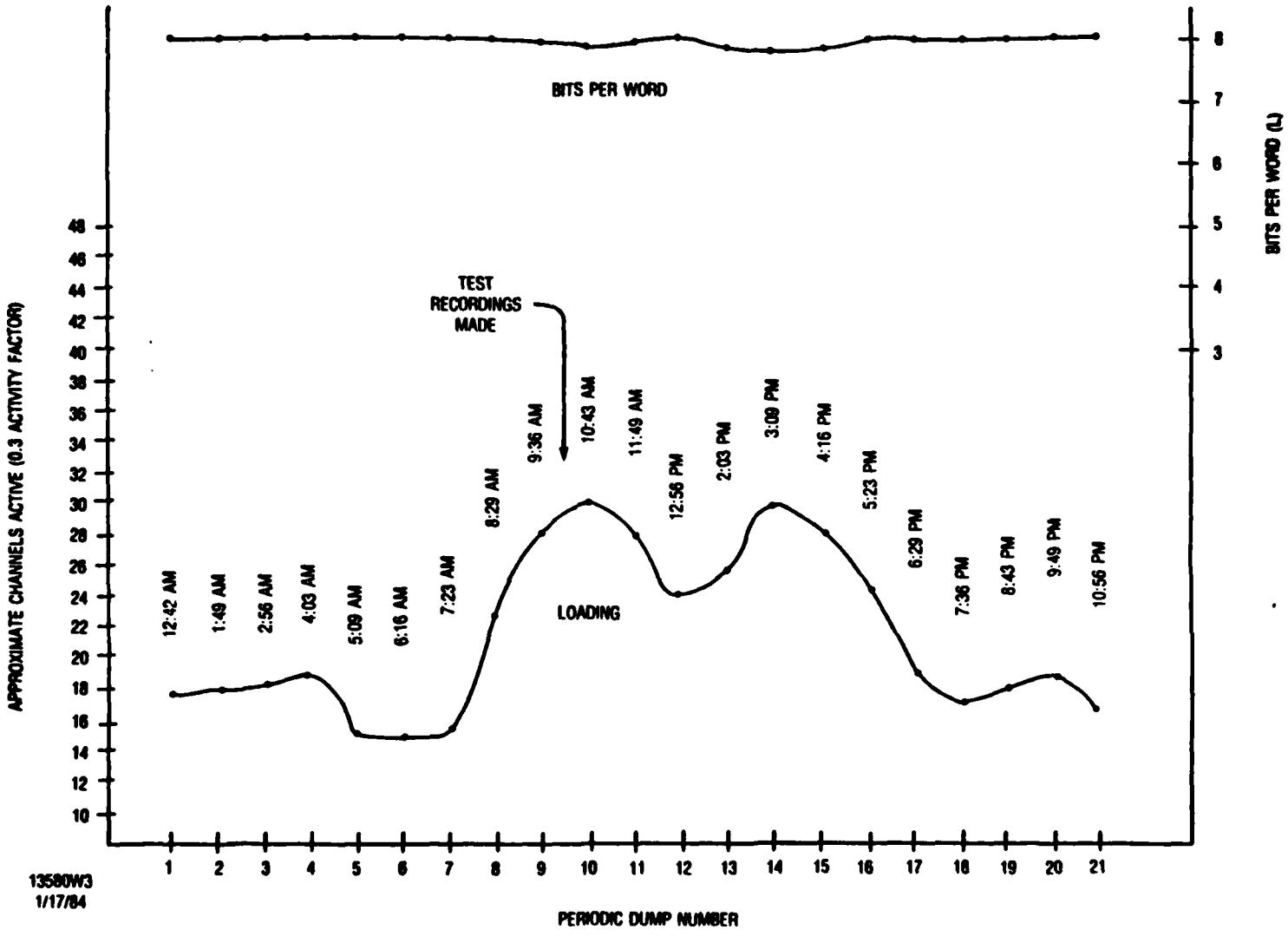


Figure 4-3. Traffic Analysis - Friday September 30, 1983

Table 4-4. Speech Statistics - Friday September 30, 1983

	Time	Ave. Spch	Ave. Data	Ave. L	Ave. Data Sent as Speech	Offhook Before DSI
	12:42 am	1.19	13.68	8.0	0.01	17.65
	1:49 am	1.15	14.12	8.0	0.02	17.95
	2:56 am	1.16	14.41	8.0	0.03	18.28
	4:03 am	1.39	14.46	8.0	0.03	19.09
	5:09 am	0.29	14.18	8.0	0.10	15.15
	6:16 am	0.24	14.09	8.0	0.00	14.89
	7:23 am	0.32	14.19	8.0	0.01	15.26
	8:29 am	2.23	15.18	7.98	0.52	22.61
Time of	9:36 am	3.84	15.43	7.92	0.65	28.23
Recordings	10:43 am	4.40	15.45	7.84	0.68	30.12
	11:49 am	3.84	15.50	7.91	0.70	28.3
	12:56 pm	2.61	15.51	7.98	0.82	24.21
	2:03 pm	3.10	15.49	7.97	0.86	25.82
	3:09 pm	4.21	15.80	7.81	2.20	29.83
	4:16 pm	3.89	15.52	7.91	0.86	28.49
	5:23 pm	2.59	15.57	7.97	0.87	24.20
	6:29 pm	1.48	15.29	8.0	0.57	20.22
	7:36 pm	0.88	14.40	8.0	0.01	17.33
	8:43 pm	1.02	14.56	8.0	0.03	17.96
	9:49 pm	1.33	14.32	8.0	0.03	18.75
	10:56 pm	0.74	14.18	8.0	0.00	16.65

Daily Averages Spch = 2.0 Channels

Data = 14.83 Channels

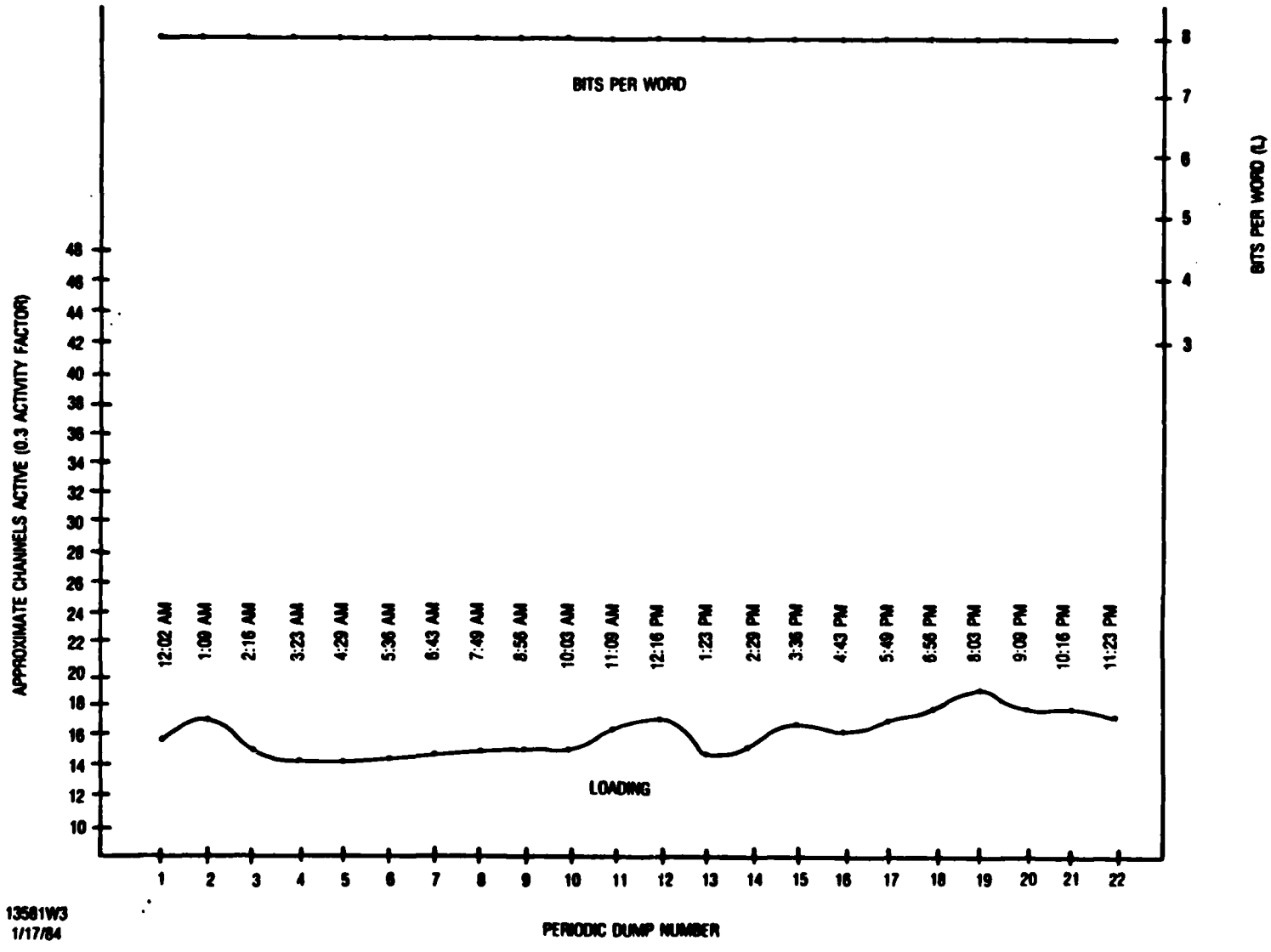


Figure 4-4. Traffic Analysis - Saturday October 1, 1983

Table 4-5. Speech Statistics - Saturday, October 1, 1983

Time	Ave. Spch	Ave. Data	Ave. L	Ave. Data Sent as Speech	Offhook Before DSI
12:02 am	0.48	14.15	8.0	0.05	15.75
1:09 am	0.65	14.83	8.0	2.12	17.00
2:16 am	0.15	14.16	8.0	0.17	14.66
3:23 am	0.08	14.09	8.0	0.00	14.36
4:29 am	0.06	14.08	8.0	0.01	14.28
5:36 am	0.07	14.21	8.0	0.00	14.44
6:43 am	0.17	14.18	8.0	0.00	14.75
7:49 am	0.21	14.14	8.0	0.01	14.84
8:56 am	0.18	14.81	8.0	0.01	15.41
10:03 am	0.23	14.01	8.0	0.00	14.78
11:09 am	0.49	14.61	8.0	0.02	16.24
12:16 pm	0.72	14.56	8.0	0.01	16.96
1:23 pm	0.17	14.08	8.0	0.00	14.65
2:29 pm	0.30	14.38	8.0	0.01	15.38
3:36 pm	0.37	15.17	8.0	0.09	16.40
4:43 pm	0.30	15.07	8.0	0.05	16.07
5:49 pm	0.51	15.25	8.0	0.13	16.95
6:56 pm	0.80	14.89	8.0	0.12	17.56
8:03 pm	1.47	14.45	8.0	0.05	19.35
9:09 pm	0.96	14.51	8.0	0.01	17.71
10:16 pm	1.12	14.25	8.0	0.01	17.98
11:23 pm	0.85	14.36	8.0	0.01	17.19

Daily Averages Spch = 0.47 Channels
Data = 14.47 Channels

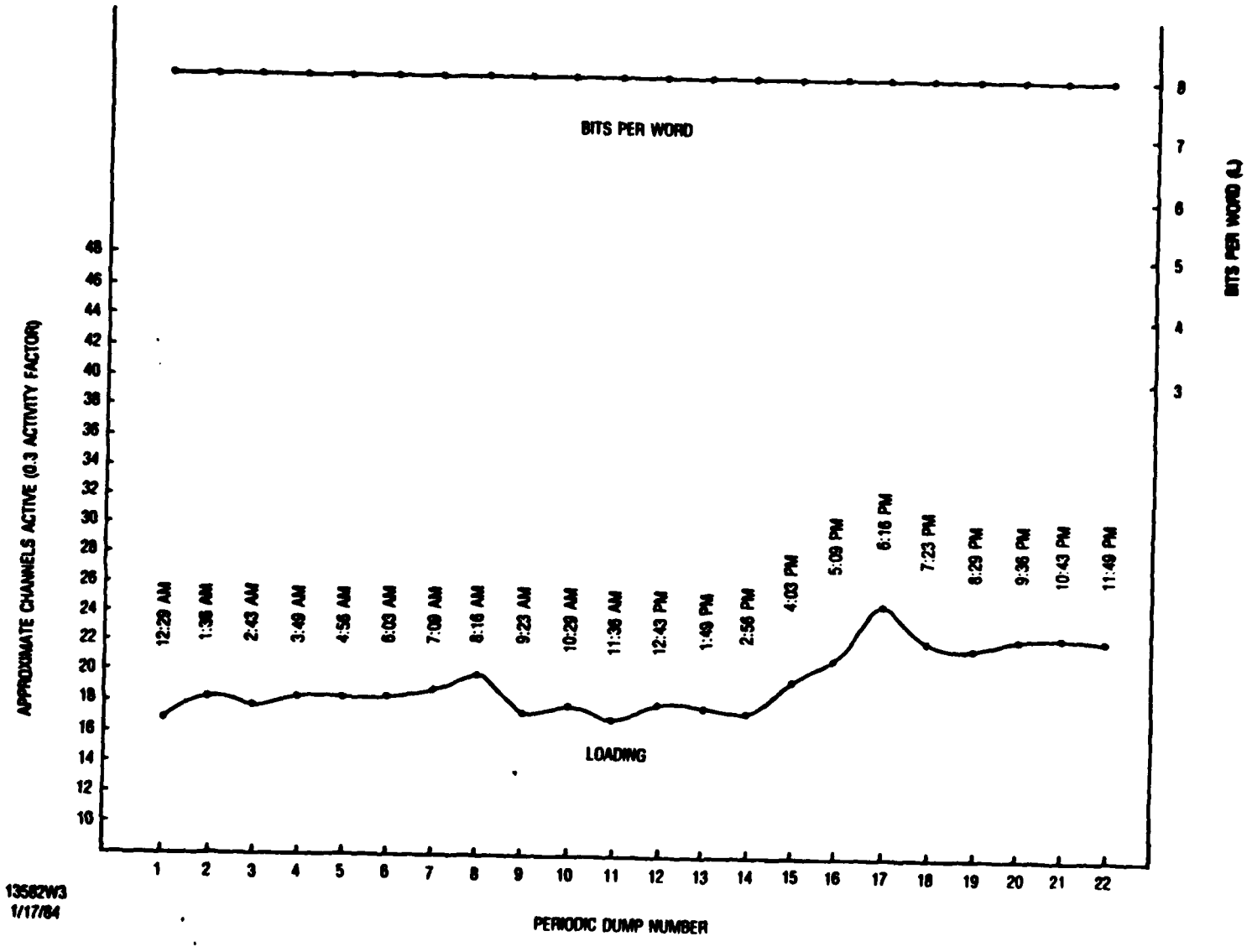


Figure 4-5. Traffic Analysis - Sunday October 2, 1983

Table 4-6. Speech Statistics - Sunday, October 2, 1983

Time	Ave. Spch	Ave. Data	Ave. L	Ave. Data Sent as Speech	Offhook Before DSI
12:29 am	0.71	14.69	8.0	0.01	17.06
1:36 am	0.97	15.32	8.0	0.32	18.55
2:43 am	0.87	14.96	8.0	0.23	17.86
3:49 am	1.11	14.77	8.0	0.05	18.40
4:56 am	1.07	14.80	8.0	0.03	18.37
6:03 am	1.16	14.71	8.0	0.04	18.58
7:09 am	1.29	14.75	8.0	0.09	19.05
8:16 am	1.43	15.32	8.0	0.20	20.09
9:23 am	0.79	14.83	8.0	0.06	17.46
10:29 am	1.06	14.65	8.0	0.05	18.18
11:36 am	0.73	14.73	8.0	0.04	17.16
12:43 am	0.93	15.18	8.0	0.25	18.28
1:49 pm	1.01	14.45	8.0	0.07	17.82
2:56 pm	0.95	14.35	8.0	0.01	17.52
4:03 pm	1.31	15.37	8.0	0.21	19.74
5:09 pm	1.66	15.55	8.0	0.22	21.08
6:16 pm	2.76	15.73	8.0	0.49	24.93
7:23 pm	1.93	15.74	8.0	0.48	22.17
8:29 pm	1.84	15.71	8.0	0.39	21.84
9:36 pm	2.14	15.58	8.0	0.40	22.71
10:43 pm	2.08	15.67	8.0	0.58	22.60
11:49 pm	2.02	15.6	8.0	0.44	22.33

Daily Averages Spch = 1.36 Channels
Data = 15.11 Channels

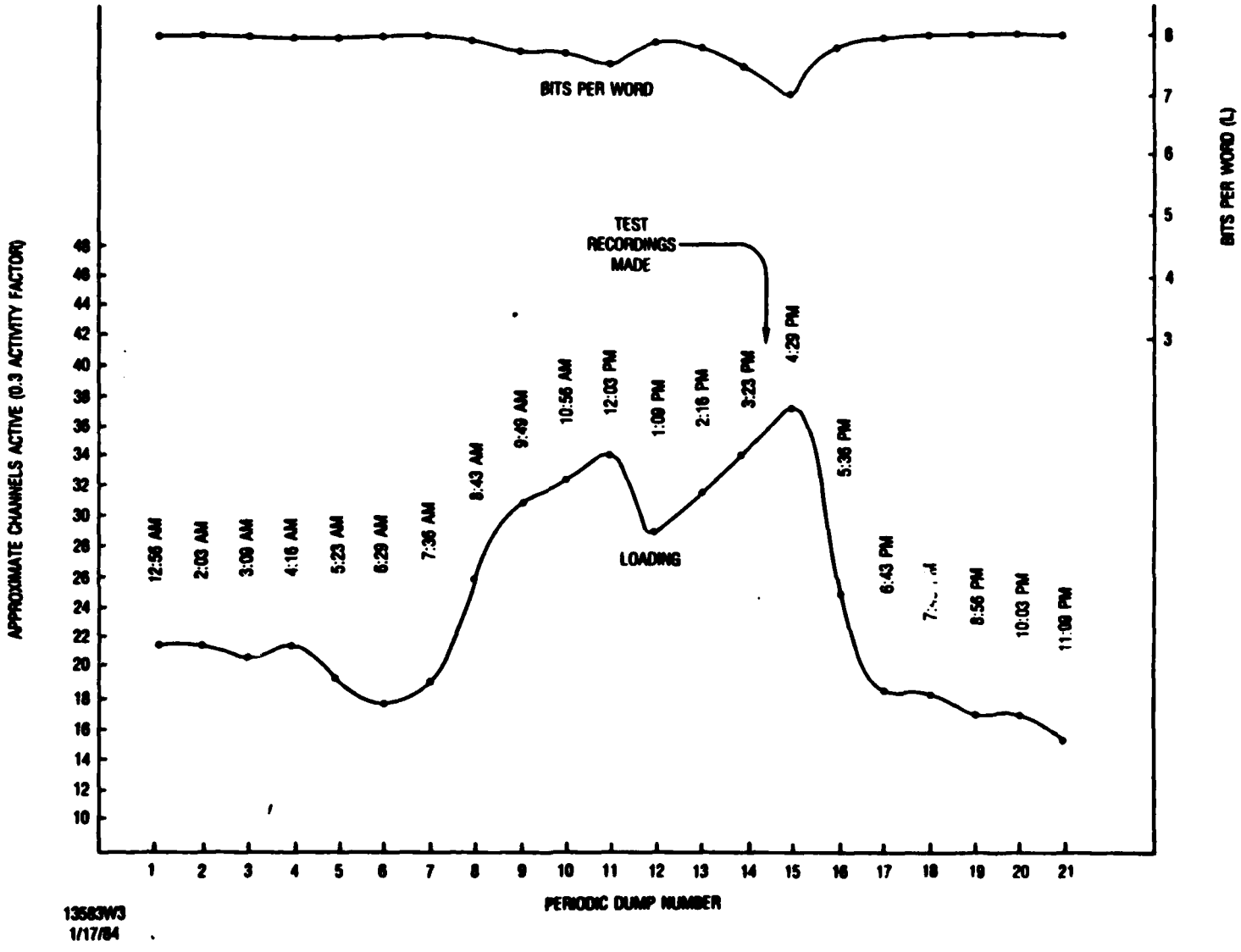


Figure 4-6. Traffic Analysis - Monday October 3, 1983

Table 4-7. Speech Statistics - Monday, October 3, 1983

	Time	Ave. Spch	Ave. Data	Ave. Ave. L	Data Sent as Speech	Offhook Before DSI
	12:56 am	1.92	15.48	8.0	0.43	21.88
	2:03 am	1.82	15.69	8.0	0.50	21.76
	3:09 am	1.52	15.67	8.0	0.53	20.74
	4:16 am	1.76	15.76	8.0	0.68	21.63
	5:23 am	1.15	15.56	8.0	0.50	19.39
	6:29 am	0.88	14.80	8.0	0.08	17.73
	7:36 am	1.24	14.76	8.0	0.08	18.89
	8:43 am	3.22	15.41	7.96	0.54	26.14
	9:49 am	4.54	15.76	7.74	1.60	30.89
	10:56 am	4.86	16.07	7.79	3.05	32.27
	12:03 pm	5.50	16.10	7.55	6.82	34.43
	1:09 pm	3.88	16.15	7.92	4.40	29.08
	2:16 pm	4.66	16.11	7.76	3.44	31.64
Time of	3:23 pm	5.34	16.20	7.59	3.70	34.0
Recordings	4:29 pm	6.44	16.27	7.12	8.76	37.74
	5:36 pm	2.64	16.21	7.96	4.22	25.01
	6:43 pm	0.91	15.39	8.0	0.43	18.42
	7:49 pm	1.03	14.90	8.0	0.16	18.33
	8:56 pm	0.63	14.68	8.0	0.08	16.78
	10:03 pm	0.76	14.70	7.98	0.55	17.23
	11:09 pm	0.29	14.30	8.0	0.04	15.27

Daily Averages Spch = 2.62 Channels

Data = 15.52 Channels

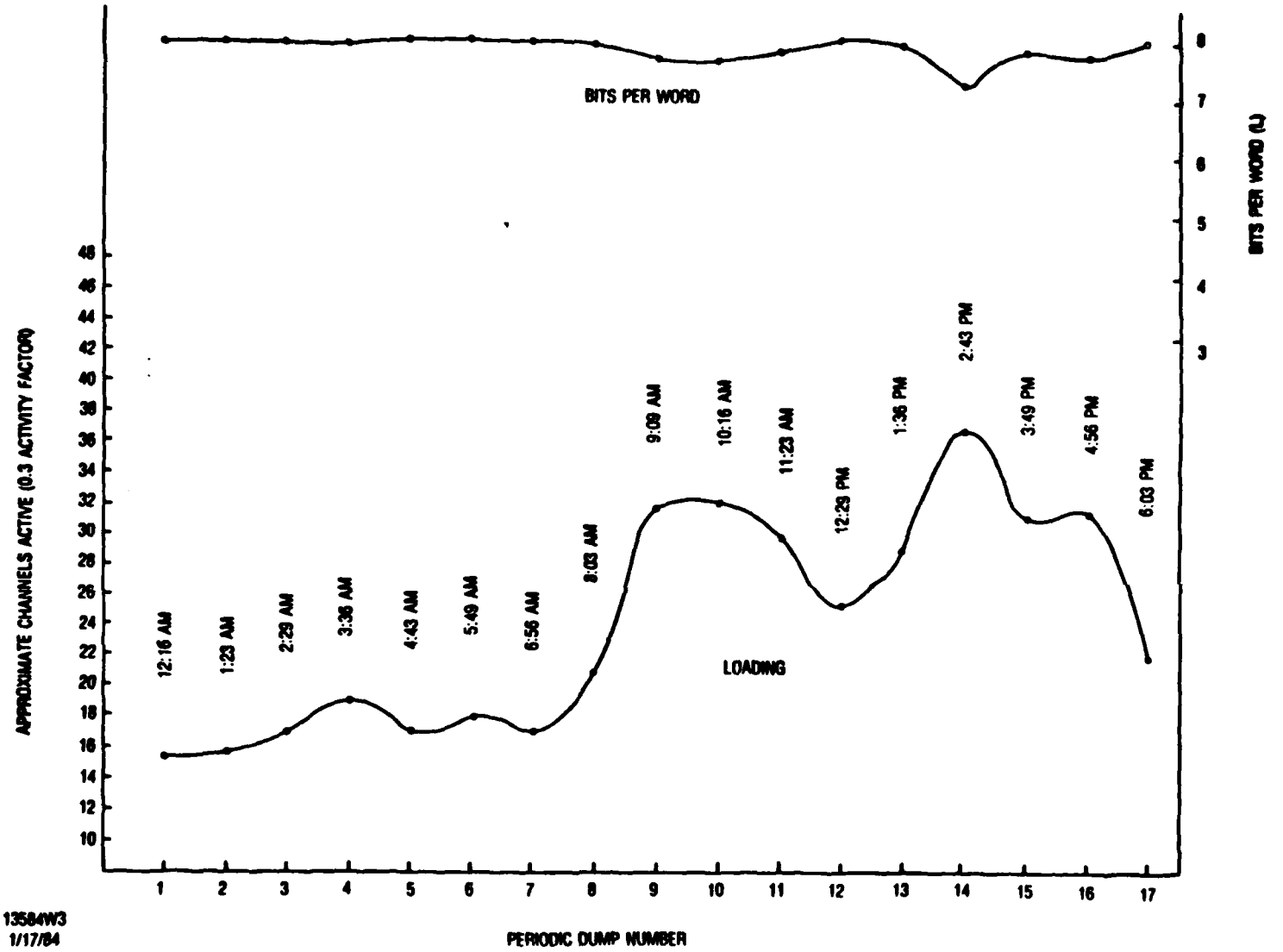


Figure 4-7. Traffic Analysis - Tuesday October 4, 1983

Table 4-8. Speech Statistics - Tuesday October 4, 1983

Time	Ave. Spch	Ave. Data	Ave. L	Ave. Data Sent as Speech	Offhook Before DSI
12:16 am	0.37	14.30	8.0	0.03	15.53
1:23 am	0.33	14.76	8.0	0.10	15.86
2:29 am	0.44	15.44	8.0	0.35	16.91
3:36 am	1.09	15.70	8.0	0.94	19.33
4:43 am	0.60	15.11	8.0	0.27	17.11
5:49 am	0.81	15.64	8.0	0.75	18.34
6:56 am	0.46	15.31	8.0	0.28	16.84
8:03 am	1.79	14.87	7.98	0.32	20.84
9:09 am	4.75	15.79	7.78	1.26	31.62
10:16 am	4.81	15.70	7.77	1.18	31.73
11:23 am	4.43	15.10	7.86	0.61	29.87
12:29 pm	3.22	14.26	7.99	0.11	24.99
1:36 pm	4.14	15.19	7.90	0.50	28.99
2:43 pm	6.26	16.06	7.32	10.69	36.93
3:49 pm	4.45	15.92	7.85	1.67	30.75
4:56 pm	4.61	16.17	7.72	2.87	31.54
6:03 pm	1.82	15.59	7.99	1.10	21.66
7:09 pm	1.67	14.76	8.0	0.41	20.33

Daily Averages Spch = 2.56 Channels
Data = 15.32 Channels

SECTION 5.0

CONCLUSIONS OF RECOMMENDATIONS

5.1 INTRODUCTION

The DCEM was designed and developed according to the Prime Item Development Specification. The extensive test program conducted on the DCEM units demonstrated the DCEM ability to meet the technical requirements set forth in the specification. In addition the DCEM met the MTBF of 3500 hours, the 12 minute MCT, and the MIL-STD-462 EMI test requirements.

5.2 PROBLEMS AND RECOMMENDATIONS

The following problems were encountered during the testing program.

5.2.1 Jitter

There were no jitter requirements placed on the DCEM per the Prime Item Development Specification. However, during tests conducted by British Telcom at Mildenhall RAF, U.K. and tests conducted by SATCOMA out of Fort Monmouth, N.J. the DCEM was unable to track large amounts of input jitter. It was determined that this could be a problem to potential users of the DCEM. As a result of this problem a design change will be implemented in the DCEM clock recovery circuitry. This will enable future DCEM units to operate with jittery input signals. The design modification will enable the DCEM to meet the jitter requirements established by CCITT for the 2.048 Mbps

interface (see Figure 5-1) and the Bell System requirements (shown in Figure 5-2) for the 1.544 Mbps interface.

5.2.2 Baud Rate Selection Switch

Currently the baud rate selection switch is located in such a way that it is not accessible without powering down the unit. This will be taken into consideration in future printed circuit card layouts. The switch will be repositioned such that it may be adjusted without affecting normal operation.

5.2.3 Chassis

During the testing program it was mentioned that the length of the DCEM should be changed. It was felt that the 24" of length was perhaps too long to fit properly into a standard rack. While testing at Ramstein AFB, the DCEM units were able to fit completely inside of the AN/FCC-98 racks. It was also suggested that using the same connectors as used on the AN/FCC-98 (Twin BNC) would be more convenient than the D type connector arrangement now used. M/A-COM DCC feels the current arrangement is adequate; however, we are open to suggestions and will consider any comments on improvements to the DCEM mechanical configuration.

5.3 GENERAL RECOMMENDATIONS

5.3.1 Commercial Units

Preliminary studies have indicated that replacement of the military standard high reliability parts in the DCEM with commercial parts would provide both a significant reduction in material cost and a significant improvement in procurement lead times at the cost of

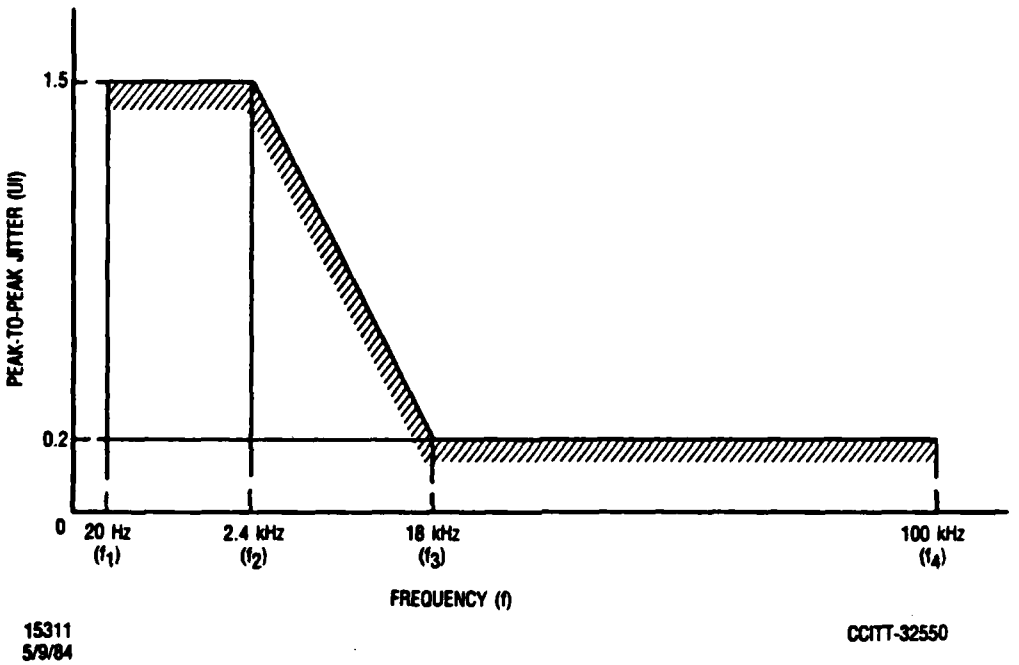


Figure 5-1. Jitter Requirements 2.048 Mbps

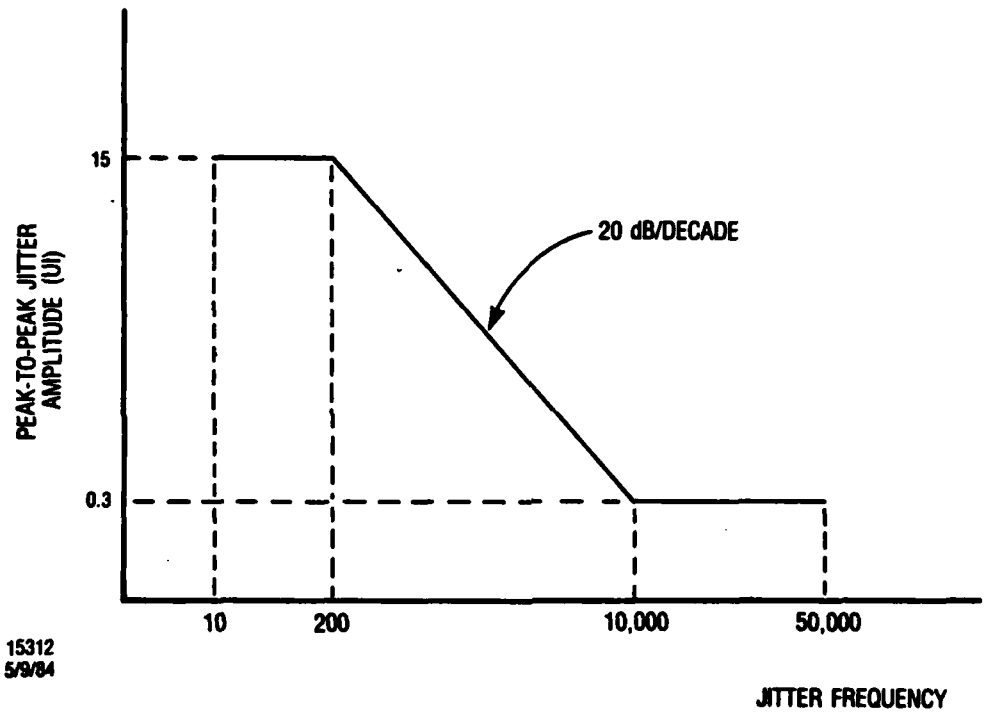


Figure 5-2. 1.544 Mbps Jitter Requirement

only a modest reduction in the MTBF. Because of this M/A-COM DCC plans to market both a military and commercial version of the DCEM. This will provide the potential users of the DCEM greater flexibility in choosing a DCEM better suited to their network requirements.

5.3.2 Division of Modes

Currently the DCEM, with its nine modes of operation, solves a variety of conversion and capacity problems. This combining of modes into one unit has the advantage that many different problems can be solved with this one box. For application where only a few units are required, there is an economic advantage to using a DCEM to solve the problem as opposed to developing a special unit to solve an interface problem. However, since the DCEM could not be optimized to provide only one specific function, there is hardware and software used for each specific mode of operation that would not be necessary if only one mode were required. Because of this, if there were a requirement for a large number of DCEM units for only one of the modes of operation at some point as the number of units becomes large, it may become necessary to consider developing a special unit for this one mode. As an example, M/A-COM DCC has developed a unit based on the DCEM technology which is similar to mode A. This unit can compress 96 channels into 24. Because this unit has been optimized, it only requires six PC cards where the DCEM requires nine PC cards. For large orders the DCEM would cost about 50% more than this other unit. Therefore, at some point a specialized unit will have an advantage over the DCEM.

MISSION
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Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C^3I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

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